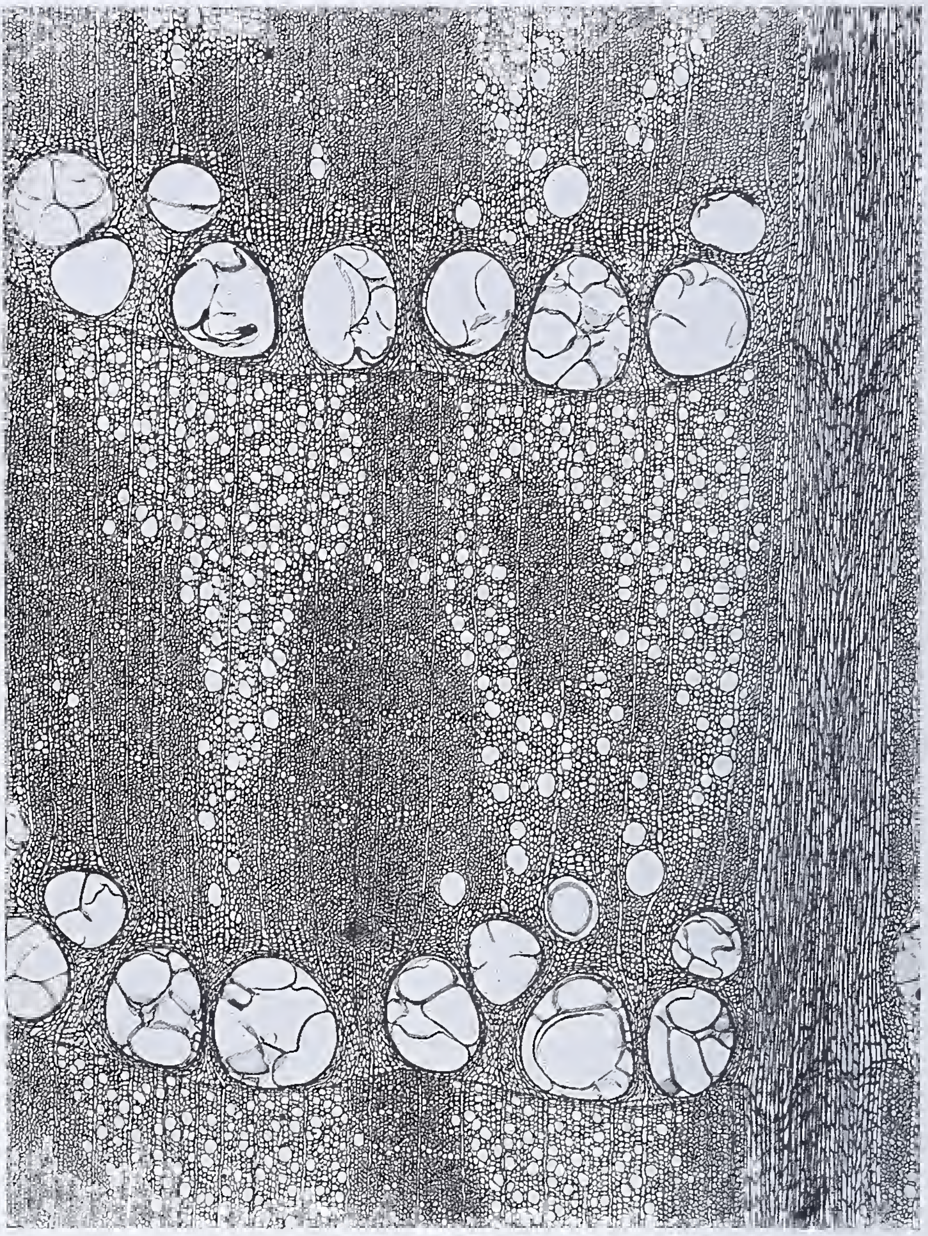
4.0/R



Quercus alba (White Oak). Cross section showing parts of three growth rings of a ring-porous wood. The early wood consists of a row of large, tylosis-filled pores, vasicentric tracheids, and paratracheal parenchyma. Composing the wide zone of late wood are dark areas of wood fibers, light areas of small pores and paratracheal parenchyma, and irregular horizontal bands of metatracheal parenchyma. Crossing the rings are numerous uniseriate rays and (at the right) one large multiseriate ray. ×35.

IDENTIFICATION *of the* TIMBERS *of* TEMPERATE NORTH AMERICA

INCLUDING ANATOMY AND
CERTAIN PHYSICAL PROPERTIES OF WOOD

BY
SAMUEL J. RECORD, M.A., M.F., Sc.D.
Professor of Forest Products, Yale University

NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited
1934

Printed in U. S. A.

Printing
F. H. GILSON CO.
BOSTON

Composition and Plates
TECHNICAL COMPOSITION CO.
CAMBRIDGE

Binding
STANHOPE BINDERY
BOSTON

PREFACE

I have written this book to replace my *Identification of the economic woods of the United States* (John Wiley & Sons, Inc., 1st ed. 1912, rev. ed. 1918), which is now out of print. It is more than a revision, as Part I has been completely rewritten and now deals with the whole field of wood anatomy, while much new material has been added to Part II. Knowledge of wood anatomy and acquaintance with the terminology are prerequisites to the use of the Key. Part I, except for some of the tables, applies to woods of both temperate and tropical climates, but Part II is concerned primarily with the commercial timbers of the non-tropical regions of the North American continent.

The anatomical terms and definitions used in this book are in conformity with those recently adopted by the International Association of Wood Anatomists. That Association had its origin in a conference of scientists at Cambridge, England, in August 1930. An Organizing Committee was appointed, and the constitution proposed by it was adopted at a second conference, held at Paris, July 4, 1931. At present twenty-three nationalities are represented in its membership, which is limited to persons actively engaged in the study of wood anatomy, and its affairs are administered by a Council of twelve, elected every three years. One of the activities of the Association is "to work toward standard terminology and descriptions."

Work on a glossary of terms used in describing woods was begun at the Cambridge conference and carried on informally until early in 1932, when it was placed under the aegis of the Association and referred to a special Committee on Nomenclature consisting of Professor Arthur J. Eames, Cornell University; Professors Irving W. Bailey, Ralph H. Wetmore, and Robert H. Woodworth, Harvard University; Professor George A. Garratt and myself (Chairman, and Secretary of the Association), Yale University. The Committee's report on 126 terms was published in *Tropical Woods* for December 1, 1933. At that time some of the latest proposals had not been acted upon by the Council, but all of them were subsequently adopted as standard for the Associa-

tion. The cordial reception of the glossary by teachers and students of plant anatomy affords assurance of its general adoption.

The Committee's published report was concise and without illustrations. In this book I have attempted, unofficially, to elaborate the definitions and to give the terms practical application. In doing so I have had the benefit of advice from members of the Committee and others to whom the first draft of the manuscript was submitted, but the responsibility for the work in its final form is my own. Rapid progress is now being made in the study of woods, and the results are proving some of the older concepts wrong and many others in need of revision. Research must proceed much further, however, before a really adequate treatise on wood anatomy can be written.

The descriptive key in Part II of this book is along familiar lines, but it has undergone a thorough revision. In the belief that identification of a specimen involves more than the mere naming of it, I have appended short accounts of each of the specific groups in the key, thereby identifying a wood more fully in both the botanical and industrial fields. It is hoped that these notes and references will prove useful, especially to dealers and consumers who often are confused by the laxity with which trade names are employed.

I am greatly indebted to the members of the Committee on Nomenclature (named above) for assistance in the preparation of Part I of this book. Two others who read the original manuscript and gave me benefit of their suggestions are Dr. L. Chalk, Imperial Forestry Institute, Oxford, England, and Dr. Irma Webber, Rubidoux Laboratory, Riverside, California. My colleague, Professor Garratt, has cooperated with me throughout. Mr. Herbert F. Marco, graduate student at the Yale School of Forestry, has assisted greatly by making photomicrographs for use in Part I. Dr. Eloise Gerry and Mr. Arthur Koehler, of the U. S. Forest Products Laboratory at Madison, Wisconsin, were also very helpful in obtaining illustrations. Nearly all of the photomicrographs used in preparing the plates at the end of the book were made by me at the Madison Laboratory in 1911 from sections prepared by Mr. Charles J. Heller while a student at Harvard University.

Samuel J. Record

March 1, 1934

CONTENTS

ILLUSTRATIONS

TABLES

IDENTIFICATION OF THE TIMBERS OF TEMPERATE NORTH AMERICA

PART I

ANATOMY AND CERTAIN PHYSICAL PROPERTIES OF WOOD

Classification of Trees

Trees yielding wood of economic importance are members of the highest subdivision of the plant kingdom — the Spermatophytes, or true seed-bearing plants. Three distinct kinds of trees are universally recognized, namely, the Gymnosperms, and the Monocotyledons and Dicotyledons of the Angiosperms.

The **Gymnosperms** were so named because the ovules, instead of being inclosed in an ovary as they are in the Angiosperms, are borne naked on the face of a bract or scale where the wind-disseminated pollen grains can reach them directly. The plants of this group are resinous trees or shrubs, mostly with evergreen needle-like or scale-like leaves. They often form extensive and sometimes nearly pure forests in the mountainous and cool temperate regions of the world and are the source of the great bulk of the timber of commerce. The woods, which are comparatively homogeneous and easy to work, are commonly called softwoods, in contrast to those of the Dicotyledons, which are known as hardwoods.*

Many forms of Gymnosperms have been long extinct; those now living are of four orders, namely, Cycadales, Gingkoales, Coniferae, and Gnetales. In North America a few Cycads, remnants of a vanishing race, are grown for decorative purposes in greenhouses or in gardens where the climate is mild; the *Gingko*,

* In the parlance of the timber trade, the terms "softwood" and "hardwood" (written as single words) have acquired technical and even legal meanings that have no reference to the actual density of the wood, but are the full equivalents of gymnospermous wood and dicotyledonous wood, respectively.

with its small, fan-shaped, deciduous leaves, has been introduced from Japan and China for occasional planting in cities; shrubs of *Ephedra* occur in northern Mexico and southwestern United States and, like the other Gnetales, are of special scientific interest because the wood has so many structural characteristics of the Dicotyledons. More than 80 per cent of the lumber produced in North America is from trees of the Coniferae. Coniferous timbers are especially well suited for structural purposes because they combine a high degree of strength and stiffness with comparatively light weight and ease of drying and manufacture; moreover, the gregarious habit of growth facilitates extensive logging operations.

The Coniferae are divisible into seven families, namely, the Taxaceae, Podocarpaceae, Araucariaceae, Cephalotaxaceae, Pinaceae, Taxodiaceae, and Cupressaceae. In the first, or Yew family, are three genera, namely, *Taxus*, *Torreya*, and *Austrotaxus;* the first two are represented in Florida and on the Pacific coast, and while their woods are of minor importance, that of the Yew (*Taxus*) is well known because of its use for archery bows. There are no members of the Podocarpaceae, Araucariaceae, and Cephalotaxaceae north of Central America; some of the species are large and valuable trees in parts of the southern hemisphere, for example, *Podocarpus* spp. in South Africa and New Zealand, and *Araucaria brasiliana* (Paraná Pine) in southern Brazil.

In the Pine family (Pinaceae) are three exotic genera (*Cedrus*, *Keteleeria*, and *Pseudolarix*) and six indigenous, namely, *Pinus* (Pine), *Picea* (Spruce), *Larix* (Larch), *Pseudotsuga* (Douglas Fir), *Tsuga* (Hemlock), and *Abies* (true Fir). With the single exception of *Pinus Merkusii*, which extends a short distance south of the equator in the Dutch East Indies, the natural ranges of all members of the Pine family are confined to the northern hemisphere. The amount of Pine lumber manufactured in the United States exceeds the combined output of all the other conifers.

The Taxodiaceae are separable into eight genera (*Taxodium*, *Sequoia*, *Glyptostrobus*, *Cryptomeria*, *Athrotaxis*, *Taiwania*, *Cunninghamia*, and *Sciadopitys*), two of which occur only in North America — *Taxodium* (Bald Cypress) in southeastern United States and in Mexico, *Sequoia* in California. The others are all Old World trees, with a single representative (*Athrotaxis*) in the southern hemisphere (Tasmania).

The true Cypresses (Cupressaceae) are of fifteen genera. Three

subfamilies are recognized, namely, THUJOIDEAE, with eleven genera: *Actinostrobus* (Australia), *Callitris* (Australia, Tasmania, New Caledonia), *Tetraclinis* (northern Africa), *Callitropsis* (New Caledonia), *Widdringtonia* (southern Africa), *Fitzroya* (Chile), *Diselma* (Tasmania), *Thujopsis* (Japan), *Thuja* (eastern Asia and North America), *Libocedrus* (California, Chile, China, New Zealand, Melanesia), and *Fokienia* (China); CUPRESSOIDEAE, with two genera: *Cupressus* (western North America, Asia, Mediterranean region) and *Chamaecyparis* (North America, Japan, Formosa); JUNIPEROIDEAE, with two genera: *Arceuthos* (Asia Minor) and *Juniperus* (North America, Europe, Asia, northern Africa). Many members of the Cypress family have scented and highly durable heartwood.

In summary, there are in temperate North America fifteen genera of Conifers, in all of which (excepting *Tumion*, or *Torreya*) are species that yield economic woods. They are of four families, namely, Taxaceae, Pinaceae, Cupressaceae, and Taxodiaceae. The Pinaceae and to a less extent the Taxodiaceae are the principal producers of structural timbers. The woods of the Taxaceae and Cupressaceae are mostly used for special purposes. Those of the Cupressaceae are scented and, together with the Taxodiaceae, are noted for their natural resistance to decay and insect attacks.

The **Angiosperms** constitute the bulk of the vegetation of the world and virtually all of the food, forage, and medicinal plants. The forms are legion and vary from low herbs to stately timber trees. The ovules and seeds are borne in a closed ovary provided with a stigma which receives the pollen grains. Pollination is effected, for the most part, through the agency of insects. The woods of all but four genera differ from those of typical Gymnosperms in having true vessels, and also exhibit much greater variety in their composition and technical properties.

The Angiosperms are readily separable into (*a*) the Monocotyledons, plants with a single cotyledon or rudimentary leaf in the embryo of the seed; and (*b*) the Dicotyledons, with two seed leaves. There are fundamental differences in the structure of their stems.

Stems of **Monocotyledons** are typically unbranched and without an outer covering of bark, and the wood is confined to slender strands, which are disposed irregularly in a mass of soft tissue (Fig. 1) and become progressively more numerous and closely compacted toward the periphery. This structure is so distinctive

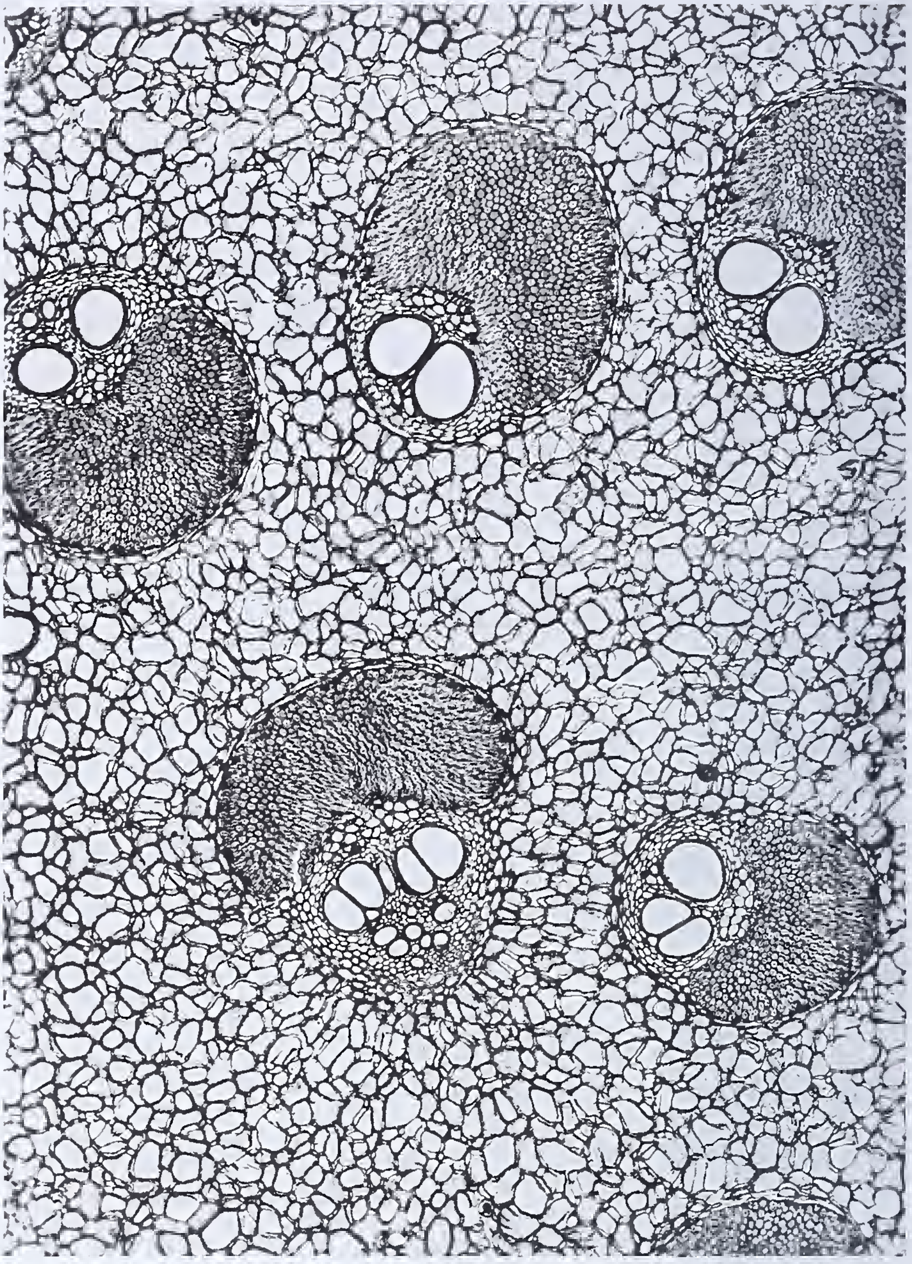


Fig. 1. — *Sabal palmetto.* Cross section of the inner part of a monocotyledonous stem showing several collateral vascular bundles, with heavy fibrous caps, imbedded in parenchymatous ground tissue. The region of the large pores is the xylem, and between it and the fibrous cap is the phloem. ×35. (Photomicrograph by U. S. Forest Service.)

that there is no occasion for confusing any portion of a monocotyledonous stem with that of either a Gymnosperm or a Dicotyledon. Some well-known representatives of the Monocotyledons are the grasses (including corn or maize, wheat, various other cereals, the bamboos, etc.), the sedges, lilies, bananas, rattans, palms, and yuccas. The tree forms are confined almost entirely to the tropics and subtropics and are there extensively used, although not in the form of lumber. Sudworth's "Check list of the forest trees of the United States"* enumerates eight genera and thirteen species of palms and ten species of yuccas as native to the southern parts of the United States. They are utilized to some extent locally, but are not a commercial source of wood, and will not be further considered in this book.

The **Dicotyledons** are much more numerous and widely dispersed than the Monocotyledons. There are about 200 families and 3000 genera containing tree forms. In temperate North America, dicotyledonous tree species outnumber all the others about nine to one, and represent 185 genera of 66 families. Most of them, however, are too small or not plentiful enough to be of economic importance. As shown in Table I, the native dicotyledonous trees contributing appreciably to the timber supply are members of only 35 genera of 21 families. U. S. Census reports on hardwood lumber production name only the following kinds: Oak (*Quercus*), Red Gum (*Liquidambar*), Maple (*Acer*), Birch (*Betula*), Yellow Poplar (*Liriodendron*), Chestnut (*Castanea*), Tupelo (*Nyssa*), Elm (*Ulmus*), Beech (*Fagus*), Basswood (*Tilia*), Ash (*Fraxinus*), Cottonwood (*Populus*), Hickory (*Hicoria*, or *Carya*), Walnut (*Juglans*), Sycamore (*Platanus*), and Cherry (*Prunus*). The first five on the list constitute about 75 per cent of the total amount; Oak alone over 30 per cent. No genus in the list is confined to the New World, although from a commercial point of view *Liquidambar*, *Liriodendron*, *Nyssa*, and *Hicoria* are essentially North American. The others are among the most common forest trees of the north temperate zone as a whole.

---

* SUDWORTH, GEORGE B.: *Check list of the forest trees of the United States; their names and ranges.* Misc. circular 92, U. S. Dept. Agr., Washington, D. C., 1927. (A revised edition of Bul. No. 17, U. S. Div. Forestry, 1898.)

TABLE I

Families and Genera of Dicotyledonous Trees Yielding Wood of Economic Importance in Temperate North America

Aceraceae
  Acer (Maple)

Aquifoliaceae
  Ilex (Holly)

Betulaceae
  Alnus (Alder)
  Betula (Birch)

Bignoniaceae
  Catalpa (Catalpa)

Cornaceae
  Cornus (Dogwood)

Ebenaceae
  Diospyros (Persimmon)

Fagaceae
  Castanea (Chestnut)
  Castanopsis (Chinquapin)
  Fagus (Beech)
  Lithocarpus (Tanbark Oak)
  Quercus (Oak)

Hamamelidaceae
  Liquidambar (Red Gum)

Hippocastanaceae
  Aesculus (Buckeye)

Juglandaceae
  Hicoria, or Carya (Hickory)
  Juglans (Walnut)

Lauraceae
  Sassafras (Sassafras)
  Umbellularia (Laurel)

Leguminosae
  Gleditsia (Honey Locust)
  Gymnocladus (Ky. Coffee-tree)
  Robinia (Black Locust)
  Prosopis (Mesquite)

Magnoliaceae
  Liriodendron (Yellow Poplar)
  Magnolia (Magnolia; Cucumber)

Moraceae
  Morus (Mulberry)
  Toxylon, or Maclura (Osage Orange)

Nyssaceae
  Nyssa (Tupelo)

Oleaceae
  Fraxinus (Ash)

Platanaceae
  Platanus (Sycamore)

Rosaceae
  Prunus (Cherry)

Salicaceae
  Populus (Cottonwood; Popple)
  Salix (Willow)

Tiliaceae
  Tilia (Basswood)

Ulmaceae
  Celtis (Hackberry)
  Ulmus (Elm)

Principal Parts of a Tree

The body of a tree consists of a continuous and more or less cylindrical axis with lateral appendages. The two principal parts of the axis are the stem (typically aërial) and the root (typically subterranean). The leaves are continuous with the stem and may be considered special expansions of it; their primary functions are to utilize the energy of sunlight in elaboration of food out of water from the soil and carbon dioxide from the air, and to promote the flow of water by evaporation. The necessary water, with certain mineral salts in solution, is absorbed by the root system and reaches the leaves through the cells of the wood known

as tracheary elements. The main stem, trunk, or bole, and its ramifications (branches, limbs, twigs) support the foliage in the light and air and provide channels for the conduction of water and the transfer of elaborated foodstuffs. Both stem and root also provide for the storage of food.

The economy of the tree is best served by a well-developed root system, a large expanse of crown, and a short, highly ramified stem, which are characteristics of trees grown in the open. To the lumberman, however, the ideal tree is one that, largely as a

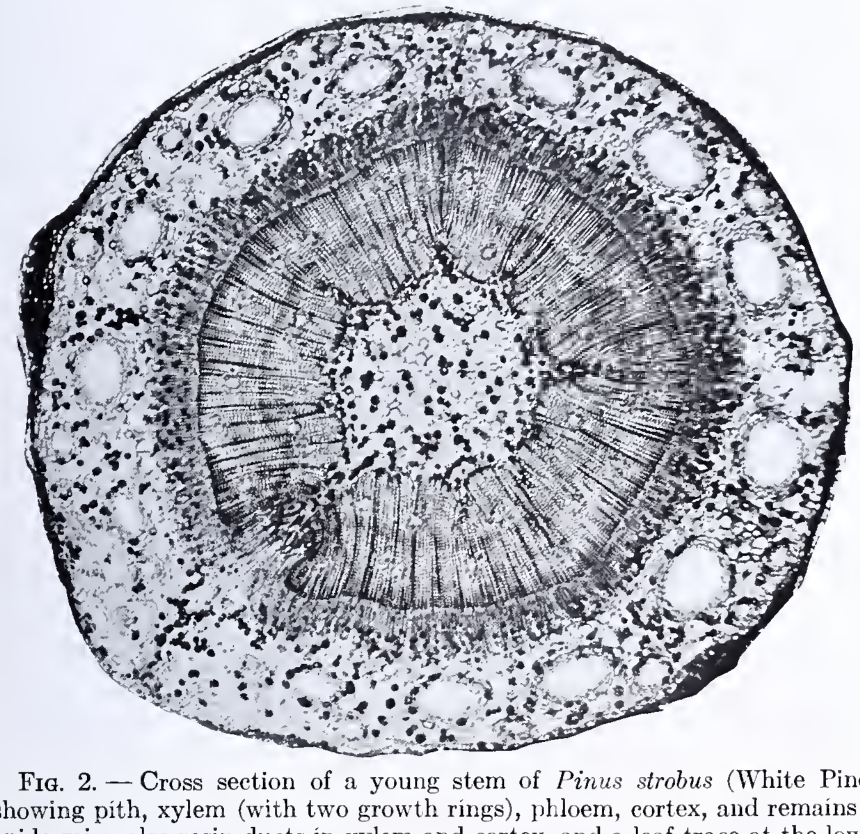


FIG. 2. — Cross section of a young stem of *Pinus strobus* (White Pine), showing pith, xylem (with two growth rings), phloem, cortex, and remains of epidermis; also resin ducts in xylem and cortex, and a leaf trace at the lower left. ×25.

result of competition in a forest, has formed a long, straight, cylindrical bole without side branches.

Since a limb is merely a subdivision of the main stem, it follows that the two are similar in structure. Limbs are more slender, however, not only because they are younger but also because their cellular elements are smaller and the seasonal accretions of wood are

narrower. They are used for cordwood and special purposes, but usually are too small and irregular for lumber. On the other hand, it generally is easier for a collector in the field to obtain specimens of them, a fact that should be taken into account in comparative studies, particularly such as involve measurements of cell size.

The root system anchors the stem to the ground and enables it to maintain its upright position, but the mechanical strain on the lateral roots is tensile rather than compressive; hence conditions are more conducive to the formation of tough bark than to the development of dense wood. Root wood, except perhaps at the

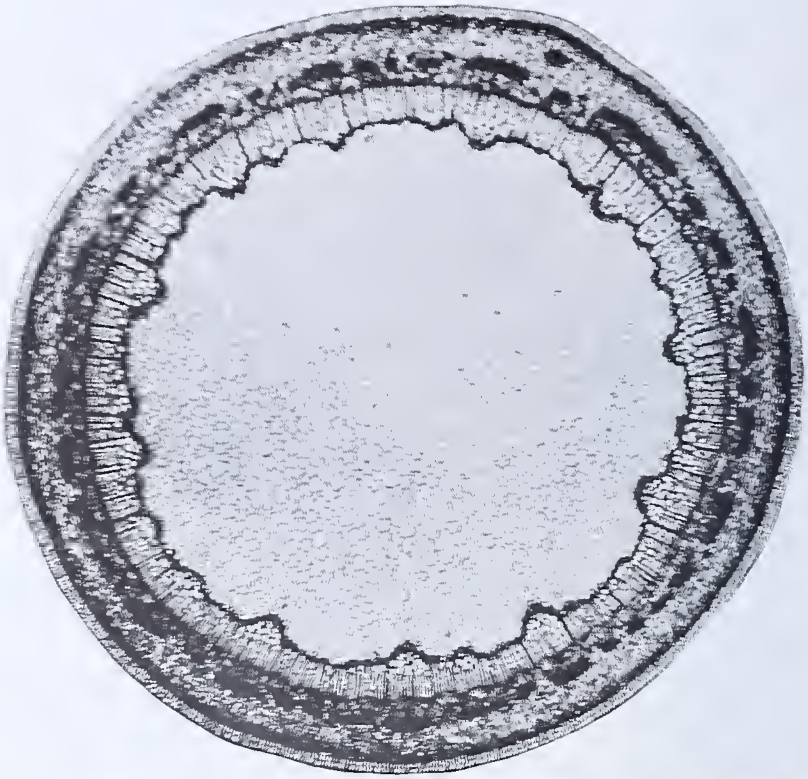


Fig. 3. — Cross section of a young stem of *Magnolia acuminata* (Cucumber Tree), showing very large pith with irregular medullary sheath; a narrow ring of primary and secondary xylem, surrounded by the bark, consisting of secondary and primary phloem, pericycle (including dark masses of sclerenchyma fibers), cortex (including dark outer ring of collenchyma), periderm (2 cells wide), and epidermis. ×17.

base of the trunk, is considerably lighter than stem wood, as the cells have thinner walls and there is a greater development of soft parenchyma tissue for food storage. A further difference is that

the roots of most species do not have a central core of pith. From an evolutionary point of view, the root is considered a more conservative region than the stem. Roots are an insignificant source of commercial timber and will be omitted from further direct consideration in this book, although many of the details of stem structure and development are also applicable to them.

A section across a young shoot of a Gymnosperm (Fig. 2) or a normal Dicotyledon (Fig. 3) will reveal three distinct parts. The center is occupied by soft tissue, the *pith*,* which is comparatively large and conspicuous. Surrounding this is a ring of harder tissue, the *wood*, and it in turn is completely enveloped by the *bark*,† which may be thicker than the wood. Older stems have the same arrangement, but the relative proportions of the three parts are different. While the size of the pith remains stationary, the woody cylinder increases enormously and soon constitutes the bulk of the stem. Eventually it becomes differentiated into an outer, light-colored layer of physiologically active *sapwood* and an inner and usually darker cylinder of *heartwood*, composed of inert elements (Fig. 4).

Although wood and bark may appear to be in contact, in reality they are separated by a thin layer of generative tissue, the *cambium*,

---

* The pith in woody stems of Gymnosperms is fairly uniform in shape, size, color, and structure; in Dicotyledons there is great variation. As to outline in cross section, it is star-shaped in *Quercus;* triangular in *Fagus*, *Betula*, and *Alnus;* ovoid in *Tilia*, *Fraxinus*, and *Acer*; circular in *Juglans*, *Ulmus*, and *Cornus*. In *Juglans* the color is black; in *Gymnocladus* it is red; in many others it is brown or gray. In *Rhus*, *Sambucus*, and *Ailanthus* the pith is comparatively large and conspicuous, often deeply colored. In *Magnolia*, *Liriodendron*, *Nyssa*, *Asimina*, and *Anona* there is often a more or less distinct septation of the continuous pith by plates of stone cells, while in *Juglans* there is decided septation but the diaphragms are not sclerotic and the pith is not continuous between the disks. On account of these and other peculiarities the pith when present in a specimen of wood is frequently an aid to identification.

† Bark is a term applied collectively to all of the tissues of the stem and root outside the cambium layer. When first formed it is composed of primary tissues, namely, primary phloem, cortex, pericycle, and epidermis. All the bark subsequently produced by the cambium is secondary phloem. The increase in size of the stem tends to rupture the bark and expose the living cells, but the successive development of secondary meristems (cork cambia) serves to protect the physiologically active cells. Bark thus becomes differentiated into two layers, *inner bark*, consisting of living tissues, and *outer bark*, of a dry corky nature. The bark of a tree is as distinctive as the wood, and its presence on specimens may permit specific identifications that would otherwise be uncertain.

which during active growth is full of sap and easily torn: this layer is the source of new wood and new inner bark, or *phloem*. The

FIG. 4. — Heartwood, sapwood, and bark of *Hicoria* (*Carya*) sp. (Hickory): Cross section (slightly reduced) showing dark-colored heartwood (*H*), light-colored zone of fine-grained sapwood (*S*), and outer covering of bark (*B*). The inner, living part of the bark is light colored, the outer, dead part is black. (Photo by U. S. Forest Service.)

seasonal additions made by the cambium to the woody cylinder are known as *growth layers* or, in cross section, *growth rings*.

The upward movement of water in a tree is mainly through the

tracheary elements of the sapwood, while the downward transfer of foodstuffs is principally through the phloem. Lateral distribution of cell sap is made possible by radially arranged sheets of tissue, the *rays*, which extend from the cambium into both wood and phloem.

All gymnospermous and normal dicotyledonous trees and shrubs have the same general structure, but differ greatly in details. (For woods with anomalous structure see p. 104.) Some of these structural variations are inherent, others are the result of environment; hence, to evaluate their diagnostic worth, it is necessary to know something about the evolution and life histories of the different elements. A logical place to begin such a study is at the growing point of the stem.

Primary Tissues

At the growing point of a stem are a few cells, essentially all alike, which give rise directly and indirectly to all the other tissues of that stem. These cells comprise what is known as the **promeristem** or *primordial meristem*.

Below the apex, the promeristem becomes differentiated into three parts, namely, the **protoderm**, the **procambial strands** or **cylinder**, and the **fundamental** or **ground meristem.** Since these three regions or tissues are themselves subject to further differentiation, they are called **primary meristems.** The protoderm develops into the epidermis; the ground meristem into the pith, pericycle, and primary cortex; the procambium into **vascular bundles.**

The primary vascular bundles are disposed in a ring about the pith, either close together or somewhat widely separated by rays of fundamental tissue, the so-called *primary medullary rays.* Each bundle has three components: (*a*) The inner part, next the pith, is the **xylem** or **wood**; this is the principal water-conducting and strengthening tissue and consists of tracheary elements and parenchyma. (*b*) The outer part is the **phloem**; this tissue is chiefly concerned with the distribution of foodstuffs elaborated in the leaves and is composed largely of sieve tubes and parenchyma. (*c*) Separating xylem and phloem is a layer of primary meristem, the **cambium.**

The part of the primary xylem formed while the stem is still elongating is known as the **protoxylem.** It is characterized by

long, tubular, unpitted, tracheary cells, whose thin walls are reinforced by annular or spiral thickenings. This structure allows the cells to be stretched without collapsing. As growth in length with its consequent stretching action ceases, the subsequent cell derivatives of the procambium are pitted and otherwise much the same as the cells produced by the cambium. This intermediate part is called the **metaxylem**. The activity of the cambium begins before all the cells of the primary wood are mature, hence there is no sharp line of demarcation between metaxylem and secondary wood. Usually, however, tissues derived from cambium can be recognized by the radial arrangement of the cells.

Some plants, structurally and functionally complete, consist wholly of primary tissues. In Gymnosperms and perennial Dicotyledons, however, primary growth is chiefly concerned with the lengthening of the axis; increase in diameter is almost wholly secondary growth. The activity of the cambium subordinates and may eventually dispose of all the primary parts of a stem except the primary xylem and the pith. Although the actual amount of primary wood is always very small and in large stems relatively infinitesimal, it is of much scientific interest because of the ancestral characters it presumably retains.

Origin and Development of Secondary Tissues

During the development of a vascular bundle, the cells of the primary xylem and phloem mature progressively toward the middle of the procambial strand. In the type of plants under consideration, the last procambial cells between the two converging tissues do not transform into permanent xylem and phloem, but remain meristematic as a lateral cambium.

If the vascular bundles are well defined, the cambium is first active in adding secondary elements to the groups of primary xylem and phloem; later the cambia of the isolated bundles become united across the intervening rays and form a continuous sheath.* In many stems, however, the groups of primary xylem make their appearance close together, there are no wide rays, and the cambium arises as a ring.

The term cambium, in its strictest usage, is applied to a tissue,

---

* The cambium of an isolated bundle is often called *fascicular*, and that across a medullary ray between two bundles, *interfascicular*.

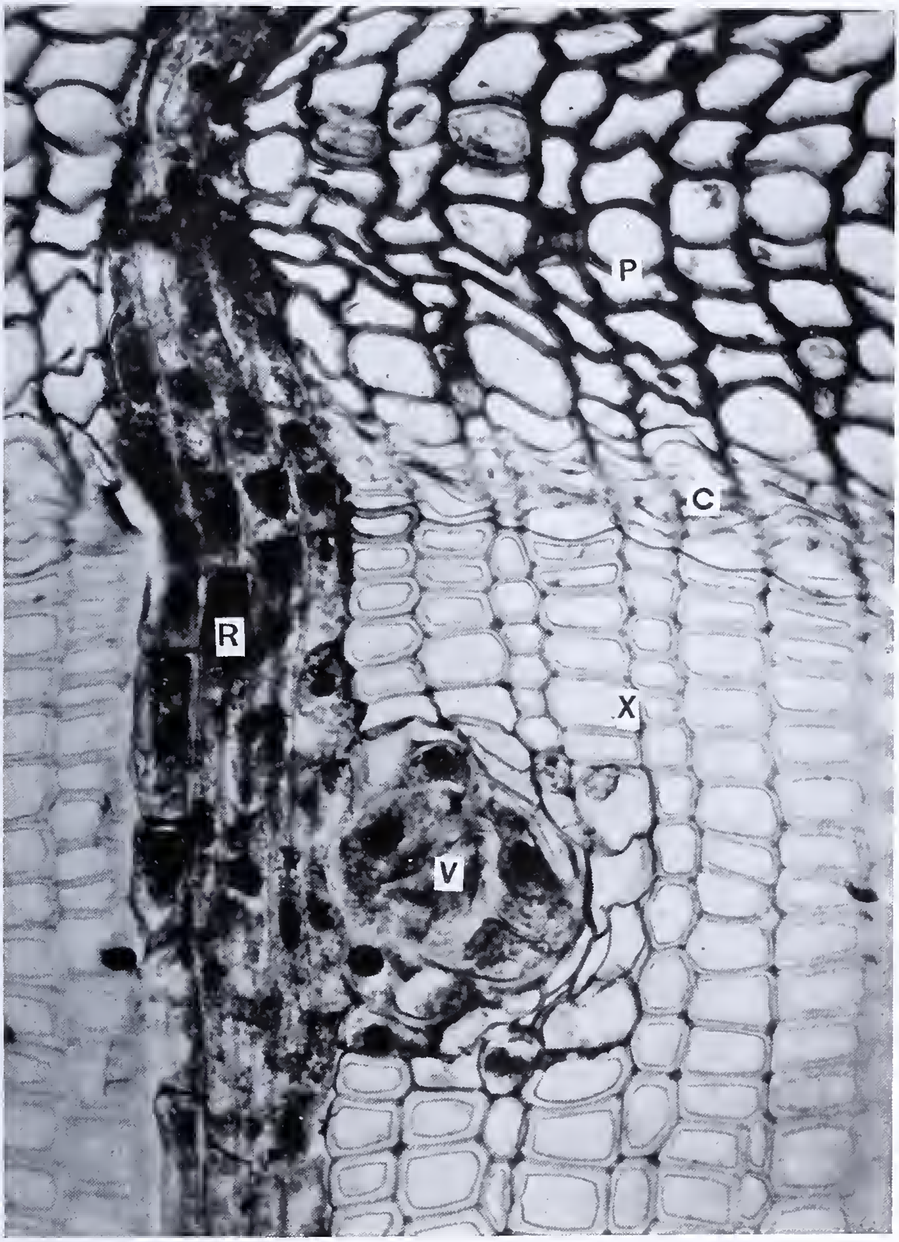


FIG. 5. — Xylem, cambium, and phloem of *Pinus monticola* (Western White Pine). Cross section showing xylem (*X*), cambial zone (*C*), and phloem (*P*). At the left is a radial resin duct (*R*) in contact with a vertical duct (*V*) that has not yet opened; the epithelial cells contain protoplasm and nuclei. ×250. (Photomicrograph by U. S. Forest Service.)

only one cell thick in cross section, composed of uninucleate cells that retain their meristematic property indefinitely. The in-

dividual cells of it and other meristems are called **initials.** The initials and their undifferentiated derivatives constitute a **cambial zone** of varying width (Fig. 5). Cambial initials may divide either transversely or longitudinally, but inasmuch as the principal direction of growth is radial, the tangential longitudinal division is by far the more common.

Initials are of two distinct types, namely, **fusiform* initials,** which give rise to the vertical or axial elements of xylem and phloem, and **ray initials**, which originate the radially disposed sheets of cells known as **rays.** Ray cell initials, although sometimes solitary, are ordinarily in vertical series or vertically arranged groups of from a few to a great many cells each. In tangential section these aggregates of ray initials closely resemble sections of the mature rays to which they give rise; the cells may all be nearly isodiametric or some of them may be vertically elongated.

The two cells resulting from the tangential division of a cambial initial are seemingly identical at first, but their subsequent histories are entirely different. One of them undergoes no change other than that necessary to restore the initial. The other, if its position is internal to the initial, becomes a **xylem mother cell;** if external, a **phloem mother cell.** This process of division is repeated indefinitely, one cell always remaining a cambial initial, the other becoming a mother cell. The latter may remain a single cell or it may divide once to several times; in either case it (or its derivatives) undergoes differentiation and becomes a part of the permanent tissues of xylem or phloem.

There does not appear to be any uniform sequence in the formation of xylem and phloem mother cells, but adjacent initials divide more or less simultaneously one way or the other, thus preserving their continuity in a fairly regular sheath. The total number of cells produced during a growing season is much greater in the xylem than in the phloem; hence the annual accretions of wood are much thicker than the corresponding additions to the bark.

As the woody cylinder enlarges, the cambium and the bark are moved outward. There are two principal methods by which the cambium keeps pace with this increase in girth: (*a*) If the fusiform initials are long and overlapping, cell division is typically by

---

* Fusiform as seen in tangential section.

means of an obliquely transverse partition; the new cells then elongate, gliding by and between one another. (*b*) If the initials are short and in horizontal rows (constituting **storied cambium,** which gives rise to woods with storied structure), division is along a radial plane and the resultant cells enlarge in a lateral direction only, without gliding growth. There are various transitional methods.

The vertical derivatives of mother cells are of various kinds and functions. Some of them remain of approximately the same length as the cambial initials; in this category are the parenchyma strands, fusiform parenchyma cells, vessel members, and certain tracheids, of the xylem; and phloem parenchyma, sieve-tube members, and companion cells, of the phloem. Other derivatives, namely, fiber-tracheids, libriform wood fibers, and phloem fibers, usually become considerably longer than the initials as the result of gliding growth.* Sometimes, particularly in storied woods, the libriform fibers may attain a length from three to six times that of their initials. In Gymnosperms some of the tracheids may elongate appreciably while others do not; the average increase is about 15 per cent.

In coniferous and some dicotyledonous woods the cells retain a distinct radial alinement. In many dicotyledonous woods the great expansion of certain vascular elements flattens and otherwise distorts the surrounding cells and crowds them out of symmetrical arrangement. Some of them are partially disjoined by this pressure and preserve contact by developing narrow tubular processes; such cells are said to be **disjunctive**† (Fig. 6).

Ordinarily only initials are meristematic, but in response to injury or other special stimulus, a **secondary meristem** may develop in tissue that normally would be permanent. There are many examples of secondary meristems, but the most outstanding is the **cork cambium.** As a stem outgrows its protective epidermal layer, a cork cambium appears and cuts off the outer portions of

* The exact manner in which gliding growth takes place is not fully understood. One hypothesis is that the intercellular substance is at this stage in a semi-liquid phase, thus facilitating the necessary spacial adjustments and allowing the ends of elongating cells to slide along and between the primary walls of other cells.

† The older term *conjugate* (from the Latin *conjugare*, to unite) is obviously inappropriate for describing this condition, since it implies action in the wrong direction.

the cortex. This action may occur only once, as in *Fagus* and *Carpinus*, but usually is repeated as often as is necessary to keep the expanding stem from rupturing the living bark; thus suc-

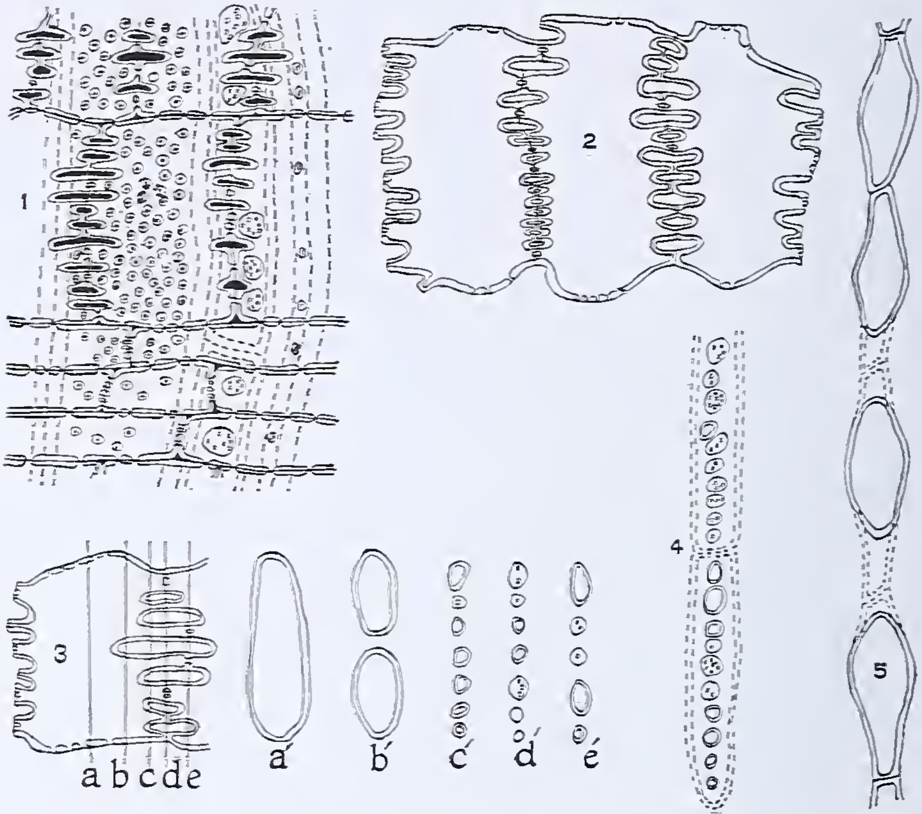


FIG. 6.—Disjunctive ray parenchyma cells in *Gardenia* sp. (1) Part of a heterogeneous ray in position, showing disjunctive upright cells and sieve-pitting between ray cells and disjunctive wood parenchyma cells. (2) Three disjunctive ray cells with middle lamella removed. (3) At the left, a disjunctive ray cell (and part of another) as seen in radial section. The five drawings (*a′* to *e′*) indicate how successive sections, first through the body of the cell at *a* and then through the processes at *b*, *c*, *d*, and *e*, would appear in tangential view. (4) Tangential section through the processes of two ray cells, the dotted lines outlining the bodies of the cells. (5) Disjunctive ray cells in cross section. Second cell from bottom appears isolated, and the dotted lines indicate the processes which, if the section is not too thin, may be brought into view by changing the focus of the microscope. ×250.

cessively deeper layers of the primary parts of the bark and eventually of the secondary phloem are cut off. In some species (*e.g.*, *Betula*), cork cambium arises in a fairly uniform layer around the stem, but more often it is localized and produces scaly or flaky bark.

Secondary Thickening of the Cell Wall

Every cell of the cambial zone consists of a protoplast inclosed by a plastic cellulose membrane called the **primary wall.** The walls of contiguous cells are not in direct contact with one another, but are separated by an amorphous layer of intercellular substance of varying thickness, which permits changes and adjustments of the cells during growth. As a differentiating cell increases in size, the primary wall is extended and becomes thinner. Since the amount of original wall material is obviously insufficient to permit the development of very large cells, additions become necessary and, presumably, are made by the introduction of new particles into the wall (intussusception).

After a xylem cell has attained its mature size its primary wall is nearly always reinforced by the deposition upon its inner face of a succession of laminae, which together constitute the **secondary wall** (or *secondary layer* of the wall). The intercellular substance becomes solidified and provides an **intercellular layer** that binds the cells firmly together. The primary wall persists, but in ordinary preparations the two primary walls of adjacent cells merge insensibly into the intercellular substance, forming what appears to be a single homogeneous layer between the main (*i.e.*, secondary) walls of the cells. For convenience this triplex layer is referred to as the **middle lamella.** Its true nature can be demonstrated by special technic, such as the use of differential stains, polarized light, etc. The thin, first-formed layer of the secondary wall, being optically anisotropic, is often mistaken for the primary wall.*

The secondary wall varies markedly in thickness and in physical and chemical properties. It is stratified, striated, and pitted. Sometimes the final thickenings are localized in the form of spiral ridges. The layers vary in their chemical and physical properties. Though usually lignified throughout, certain layers may be unlignified, gelatinous, etc.; these layers, no matter how distinct, are parts of the secondary wall, although sometimes designated as *tertiary*. The composition and structure of the secondary wall have a decided effect on the behavior of woods in drying.

---

* Much confusion has resulted from the lack of agreement among botanists, chemists, and others as to the precise meanings of such terms as *primary, secondary,* and *tertiary walls, intercellular layer,* and *middle lamella.*

Pits

During the development of the secondary wall of any cell, small gaps or recesses are left on opposite sides of the middle lamella, which facilitate the passage or diffusion of liquids. Such a recess, together with the more or less modified part of the primary wall and intercellular layer that closes it externally, is called a **pit,** and two complementary pits of adjacent cells constitute a **pit-pair*** (Fig. 7). Not infrequently in parenchyma tissue there are pits formed in the facets of the wall adjacent to intercellular spaces. Such a pit does not, of course, have a complement, and is termed a **blind pit†** (Fig. 8).

The two essentials of a pit are the **pit cavity** and the **pit membrane,** the cavity being the entire space within a pit from the membrane to the cell lumen. The shape of the cavity is made the basis for classifying pits as **simple** or **bordered.**

A **simple pit** (Fig. 8) is one in which the cavity becomes wider, or remains of constant width, or only gradually narrows during increase in thickness of the secondary wall, *i.e.*, toward the lumen of the cell. The opening into the lumen is termed the **pit aperture.** In very thick walls a simple pit usually has a narrow, **canal-like cavity.** If the thickening process proceeds far enough the canal-like cavities of two or more pits in the same horizontal plane will coalesce; such pits are called **ramiform pits‡** (Fig. 33, p. 69). Ramiform pits are characteristic of sclerotic cells (*e.g.*, stone cells and very thick-walled tyloses).

Simple pits are mostly associated with the distribution of elaborated foodstuffs. They are typical of parenchyma cells and some kinds of wood fibers. They may exhibit considerable variation in size, shape, and arrangement in the same cell, being largest in the facet of a parenchyma cell in contact with a tracheary element.

---

* *Pit-pair* is a new term coined to avoid the confusion arising from the use of the word pit for both a cellular and an intercellular structure.

† Also *air pit.* The terms *half pit* and *uniportal pit,* which have occasionally been used, are obviously inappropriate if the original definition of a pit is accepted. In some ray parenchyma cells the pits opposite *interstitial spaces* (actual openings between rounded corners of cells) often have the false appearance (in radial sections) of ending blindly against the solid secondary wall of the cell above or below.

‡ The expressions *branched pits* and pits with *branching canals* are incorrect since they imply division instead of fusion. Moreover, simple pits do not have canals.

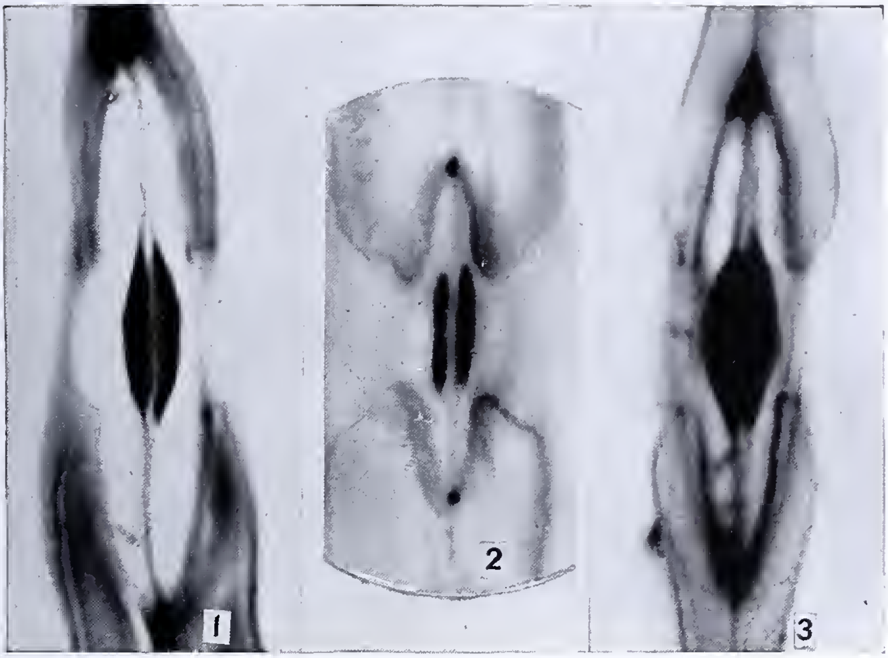


Fig. 7. — Structural details of bordered pit-pairs in *Sequoia sempervirens* (Redwood). ×3000. The chambers of the complementary pits are separated by a modified area of the middle lamella, half of which (with the thickened central disk, the torus) comprises the pit membrane of an individual pit. (1, 3) Sections of pit-pairs in early wood. (2) Section of a pit-pair in late wood. The dark spots in the upper and lower notches between the two borders are sections of the pit annulus. (Photomicrographs by I. W. Bailey.)

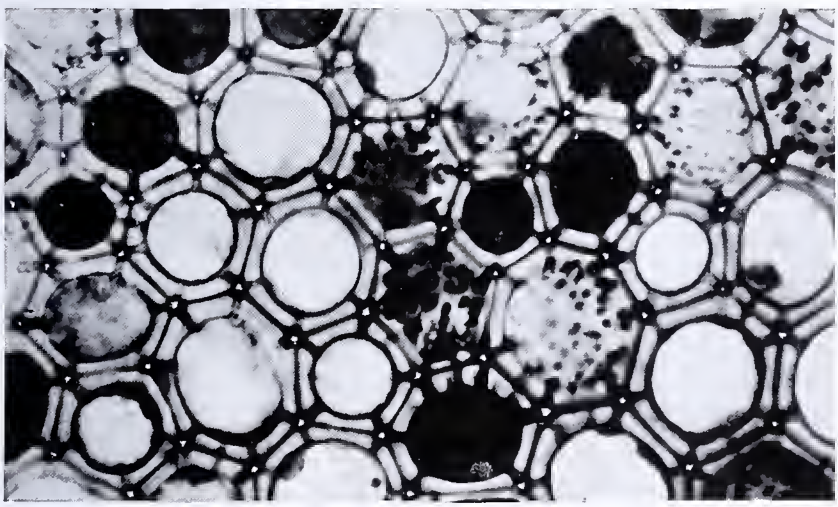


Fig. 8. — Simple pit-pairs and blind pits in ray parenchyma cells. Tangential section of a part of a multiseriate ray in *Actinidia arguta;* the blind pits are at the corners of the cells, usually three to each interstitial space. ×890.

Some parenchyma cells have elongated, parallel pits. The arrangement of small pits in cribriform clusters, as in the ends of the processes of disjunctive cells, is termed **sieve-pitting** (Fig. 6). Simple pits with funnel-shaped cavities are likely to appear bordered in surface view.

A **bordered pit** (Fig. 7) is typically one in which the cavity becomes abruptly constricted during the thickening of the wall. The wider part of the cavity, next the membrane, is the **pit chamber**, the constricted part is the **pit canal**, and the part of the wall overarching the chamber is the **border**. The opening of the canal into the lumen of the cell is the **inner aperture**, and that into the chamber of the pit is the **outer aperture**. Although a pit canal is often of the same size and shape throughout its length, it may widen as the wall thickens so that its shape becomes that of a laterally flattened funnel. In the thin-walled tracheids of the early wood of conifers, the pit borders appear as bosses on the wall and are so tapering toward the aperture that the canal virtually disappears. In very thick-walled tracheary elements (*e.g.*, the vessels in the late wood of *Hicoria* and *Diospyros*) the canals of two or more bordered pits may coalesce into one.

The middle lamella is often thicker across the gaps made by the pits than between the secondary walls. In bordered and rarely in half-bordered pit-pairs in Gymnosperms and some Dicotyledons this thicker membrane usually becomes thinned in part. The narrow unthinned rim left about the base of the border is the **pit annulus**, and the disk-shaped or lens-shaped thicker part at the center is the **torus** (Fig. 7). The latter is a little larger than the outer apertures. As a result, presumably, of unequal pressure in adjacent cells, the membrane may be pushed to one side or the other of a pit-pair so that the torus fits against the outer aperture and effectively closes the canal. The structural variations of the tori are usually not distinct enough to be readily used in the classification of woods, except in *Cedrus*, where the edges of the tori are peculiarly fringed or scalloped.

In surface view the outline of an isolated bordered pit is circular, oval, or greatly elongated with parallel sides and rounded ends. The aperture may be circular, lenticular, or linear. The orientation of an elongated aperture may be horizontal, vertical, or oblique; if obliquely inclined apertures of both members of a pit-pair are visible at the same time they will appear in the form of an

X or V. Circular pits with narrow horizontal apertures extending to the rim of the border have the appearance of screw heads and sometimes are so described. If the outline of the inner aperture crosses the border outline the aperture is said to be **extended**

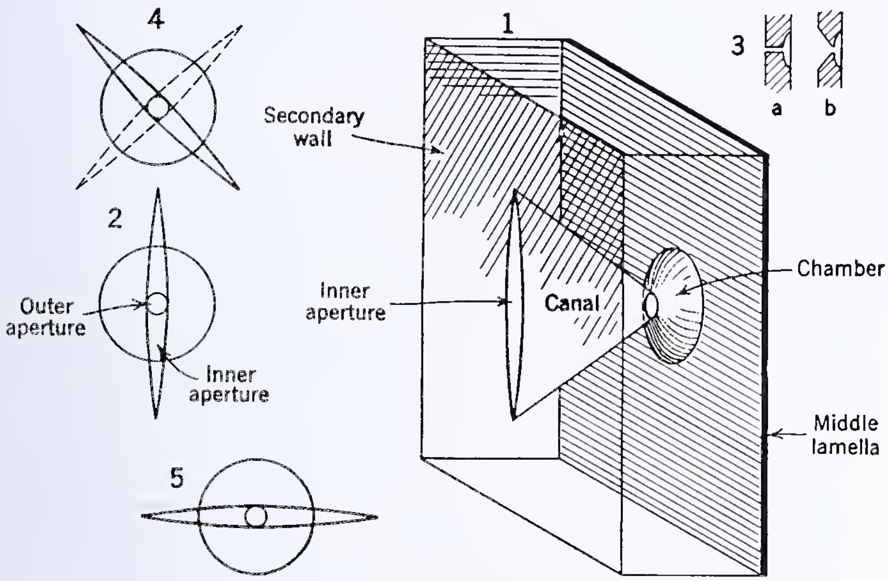


Fig. 9. — Structural details of bordered pits with extended apertures. (1) Part of a cell wall showing a dome-like pit chamber and a flattened canal. The opening of the canal into the cell lumen (the inner aperture) is here shown with its longest dimension vertical, as in the case of a fiber-tracheid with a very narrow lumen. (2) Surface view of the same pit, showing the outline of the inner aperture extending beyond the border outline. (3) Diagrams on a much smaller scale to show how the pit appears (*a*) in cross section, (*b*) in longitudinal section. (4) Same type of pit, but with the inner aperture oblique. The aperture of the complementary pit crosses it, forming an X. (5) Same type of pit, but with the inner aperture horizontal, as in certain vessels.

(Fig. 9); if it does not, it is **included** (Fig. 10). Extended inner apertures are narrowly lenticular or slit-like, and those of adjacent pits tend to coalesce, giving rise to horizontal or spiral striations or grooves; shrinkage of the wall in drying tends to prolong them.

Bordered pits characterize tracheary (*i.e.*, water-conducting) elements. They are sometimes scattered irregularly, but more often are arranged in vertical, horizontal, or oblique series. The vertical arrangement is common where the facets of the wall are narrow or the pits are greatly elongated. In the latter case the type of pitting is termed **scalariform** (Fig. 10, No. 1); it is char-

acteristic of tangential walls of the vessels of many kinds of woods (*e.g.*, *Magnolia*, *Rhizophora*). Pits in horizontal rows (*e.g.*, *Liriodendron*) are said to be **opposite** (Fig. 10, No. 2); those in oblique rows, **alternate** (Fig. 10, No. 3); the latter is the common arrangement in the large vessels of Dicotyledons and the large

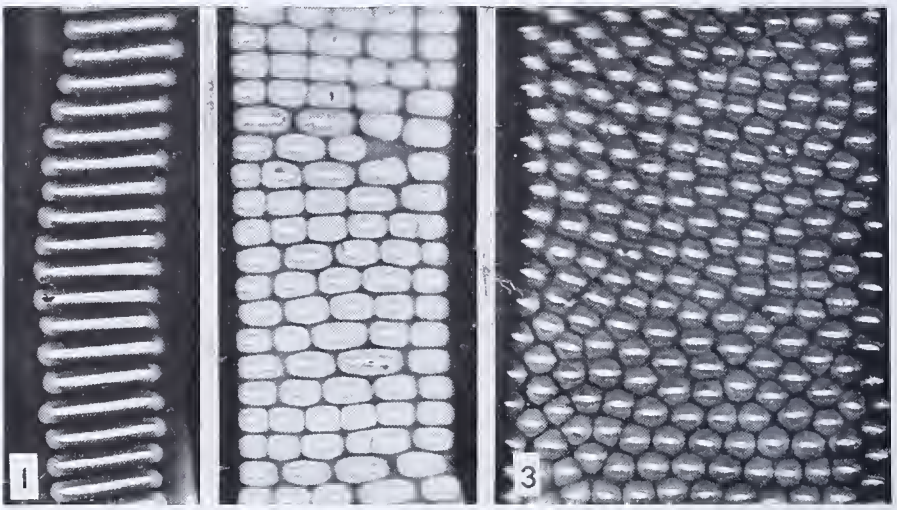


Fig. 10. — Scalariform, opposite, and alternate pitting in vessels. ×375. (1) Scalariform pitting in *Magnolia acuminata* (Cucumber Tree). (2) Opposite pitting in *Liriodendron tulipifera* (Yellow Poplar). (3) Alternate pitting in *Salix nigra* (Black Willow). The pits in all three have included apertures.

tracheids of the Araucariaceae. When crowded together, opposite pits are square or rectangular in outline, while alternate pits are hexagonal. In some instances bordered pits are distinctly clustered.

Pit-pairs are of three general types, namely, **simple, bordered,** and **half-bordered.** Pit-pairs between two parenchyma cells are simple; intervascular pit-pairs are bordered; between parenchyma and vascular elements the pit-pairs may be simple or half-bordered.* **Unilaterally compound pitting** occurs where a large pit in one cell subtends two or more smaller pits in an adjacent element.

In certain dicotyledonous woods the bordered pits have a punctate or sieve-like appearance. This formerly was ascribed to minute perforations of the pit membrane, but, according to

* According to F. H. Frost (*Bul. Torrey Botanical Club* 56: 259–263, 1929), the parenchyma member of a ray-vessel pit-pair sometimes has a narrow border.

Bailey,* it results from the presence of minute but highly refractive outgrowths from the free surfaces of the secondary wall (Fig. 11). Such pits are referred to as **vestured.** The processes are formed by the cytoplasm during the later stages of development. They vary considerably in different plants in size, number, form, and position. They may appear as papillary projec-

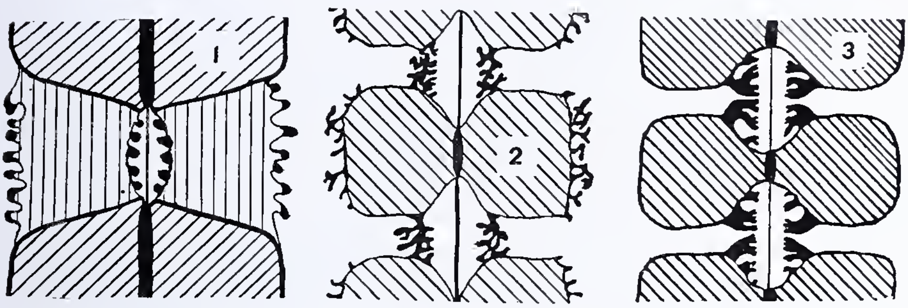


Fig. 11. — Structural details of vestured pits. (1) Sectional view of bordered pit-pair in the walls of adjacent fiber-tracheids of *Eugenia dichotoma*, showing papillary projections from the margins of both the inner and outer apertures. (2) Sectional view of two bordered pit-pairs in *Prosopis juliflora*, showing hair-like outgrowths within the pits and on the inner surface of the secondary walls of the vessels. (3) Sectional view of two bordered pit-pairs in walls of adjacent vessels of *Combretum* sp., showing coralloid outgrowths from the overarching walls of the pit chambers. (After I. W. Bailey in *Tropical Woods* 31 : 47.)

tions from the margins of both apertures, or as coralloid processes from the overarching walls of the pit chambers, or as numerous branched or anastomosing filaments lining or completely filling the entire pit cavity. Not infrequently they occur also on the inner surface of the secondary walls of the vessels. In certain species and genera the processes are confined to the intervascular pit-pairs, whereas in others they may occur also in half-bordered pit-pairs and in the bordered pits of wood fibers. In half-bordered pit-pairs they are present in the bordered pits of the tracheary elements, but not in the simple pits of the adjoining parenchymatous cells. So far as known, vestured pits are either present throughout the secondary xylem of a species or genus or are entirely absent; they frequently characterize entire families or subfamilies (Table II). Vestured pits are, therefore, of considerable

* *Tropical Woods* 31: 46–48, Sept. 1932; *Journ. Arnold Arboretum* 14: 259–293. 1933.

importance in classifying woods, but their characteristic punctate appearance may be produced by coagulated material and deposits, particularly in heartwood. Such artifacts, however, are of irregular and sporadic occurrence and lack the constancy of form of the processes of true vestured pits.

In most Gymnosperms the membranes of the bordered pit-pairs in the radial walls of the vertical tracheids differentiate within thinner areas of the middle lamella, that is, where there is comparatively little intercellular substance. Such an area is called a **primary pit field** (also *primordial pit*). A pit field may persist without the development of any pit-pairs on it, but usually there is one, often two, and sometimes three to six (Fig. 12).

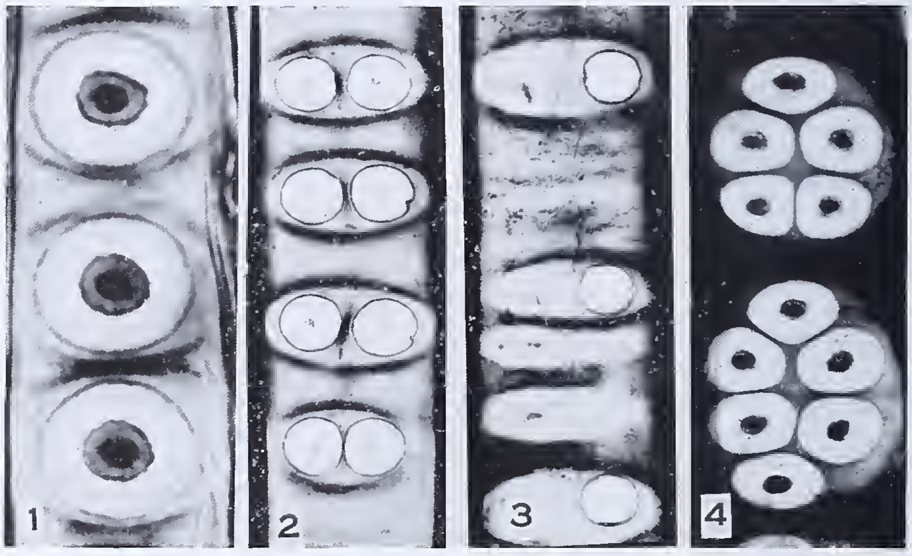


Fig. 12. — Surface views of bordered pits, crassulae, and primary pit fields in radial walls of coniferous tracheids. (1) Three bordered pits in *Pinus ponderosa*. The outer circle of each is the pit annulus; the irregular central area is the torus, with a black spot corresponding to the pit aperture; the curved lines between the pits are crassulae. ×800. (Photomicrograph by U. S. Forest Service.) (2) Four primary pit fields with two bordered pits each. The oval outlines are crassulae. ×370. (3) Three primary pit fields with a single pit each, and two with none. ×370. (4) Clustered, compressed pits in large primary pit fields in rootwood of *Cedrus*. ×400. (Last three photomicrographs by I. W. Bailey.)

In the fully differentiated secondary xylem, the intercellular substance becomes aggregated about the upper and lower margins of the primary pit fields. These transverse thickenings are now

known as **crassulae*** (Fig. 12). Only the coarser and more refractive crassulae are visible in unstained sections, and even these may be obscured in heartwood. In tracheary elements with the type of pitting characteristic of the Araucariaceae there is no room for the persistence of either primary pit areas or crassulae.

TABLE II

Occurrence of Vestured Pits in Dicotyledonous Woods*

Polygonales
- Polygonaceae

Rhoedales
- Capparidaceae
- Cruciferae

Rosales
- Leguminosae (except Bauhinieae)

Geraniales
- Malpighiaceae
- Vochysiaceae
- Euphorbiaceae (Bridelieae only)

Parietales
- Ochnaceae (Exalbuminosae only)
- Dipterocarpaceae

Myrtiflorae
- Oliniaceae

Myrtiflorae (cont.)
- Thymelaeaceae
- Lythraceae
- Sonneratiaceae
- Blattiaceae
- Crypteroniaceae
- Punicaceae
- Combretaceae
- Myrtaceae
- Melastomaceae
- Oenotheraceae

Contortae
- Oleaceae (*Nathusia*, *Forestiera*)
- Loganiaceae
- Apocynaceae
- Asclepiadaceae

Ubiales
- Rubiaceae

* According to I. W. Bailey, *Journ. Arnold Arboretum* 14: 259–293. 1933.

Tracheids and Wood Fibers

All fibrous cells of wood are popularly known as *wood fibers.* Wood anatomists, however, limit the use of that term to certain elements in Angiosperms and refer to the other fibrous xylem cells (and some also that are not fibrous) as *tracheids.* Wood fibers, in this strict sense, are presumably derivatives or modified forms of tracheids, and the two types tend to intergrade. The only morphological distinction is in the nature of the pitting.

A **tracheid** is an imperforate wood cell with bordered pits. There are several kinds of tracheids, but they all develop in much the same manner; that is, they are derived either directly from the cambium or indirectly through mother-cell division; they grow to mature size, with or without appreciable elongation; they form a secondary wall and immediately thereafter (with rare exceptions) lose their protoplasts.

* The term *crassulae* (Latin for little thickenings) has been proposed to replace both *bars* and *rims* of *Sanio.*

In the Gymnosperms there are three principal kinds of tracheids, namely, *ordinary tracheids*, vertically elongated cells composing the ground mass of the wood of all species; *strand tracheids*, short forms of infrequent occurrence; and *ray tracheids*, characteristic of several genera, mostly Pinaceae (see *Rays*).

Ordinary tracheids vary in length from 0.5 mm. to 11 mm. They are arranged in definite radial rows and may either be virtually all alike or exhibit more or less pronounced variation during the growth of a season. If seasonal layers are clearly differentiated, the tracheids of the early wood are comparatively thin walled, their ends are blunt and frequently are curved, and the apertures of the bordered pits in the radial walls are rounded in outline and included; whereas in the late-formed layer the secondary wall is thick, the cells taper gradually to a point, the inner apertures of the bordered pits in the radial walls are lenticular and usually extended, and the tracheids in the outermost rows are much flattened and their tangential walls are nearly always pitted even though those of the other tracheids are not. Typical late-wood tracheids are properly designated as *fiber-tracheids*, although the application of that term frequently is restricted to dicotyledonous woods. In some woods (*e.g.*, *Taxus*, *Torreya*, *Amentotaxus*, *Pseudotsuga*) the tracheids, wholly or in large part, are characterized by spiral thickenings.

In radial and cross sections of the wood of any Gymnosperm it is not uncommon to find small bars, or **trabeculae**, extending across the lumina of the ordinary tracheids from one tangential wall to another. Occasionally they appear in single tracheids, but usually they are in a horizontal line traversing a long radial series of cells. The typical form of a bar is that of a simple cylinder slightly enlarged at the points of contact with the secondary wall in the large cells of early wood and becoming thicker and more spool-shaped in the late wood. Trabeculae originate in the cambium as delicate threads and are subsequently covered by a secondary wall in the same manner as the rest of the cell. They have no known function, and as they are sporadic in all Gymnosperms (and possibly all Dicotyledons also, Fig. 13) they are without diagnostic value.

During the transformation of sapwood into heartwood, material of a resinous nature may be excreted by parenchyma cells into the vertical tracheids, lining their cavities and sometimes forming

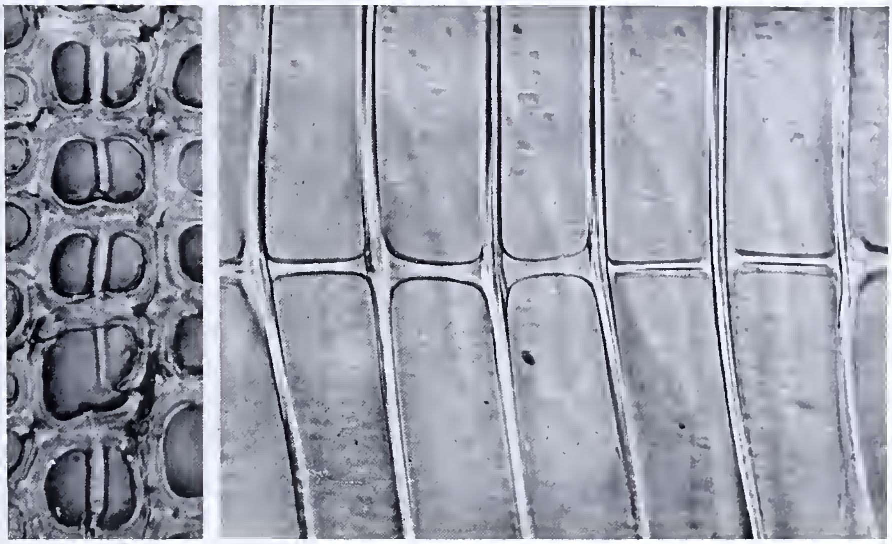


FIG. 13. — Trabeculae in the fibers of a dicotyledonous wood, *Hernandia ovigera*. Cross section at the left, radial at the right. ×555.

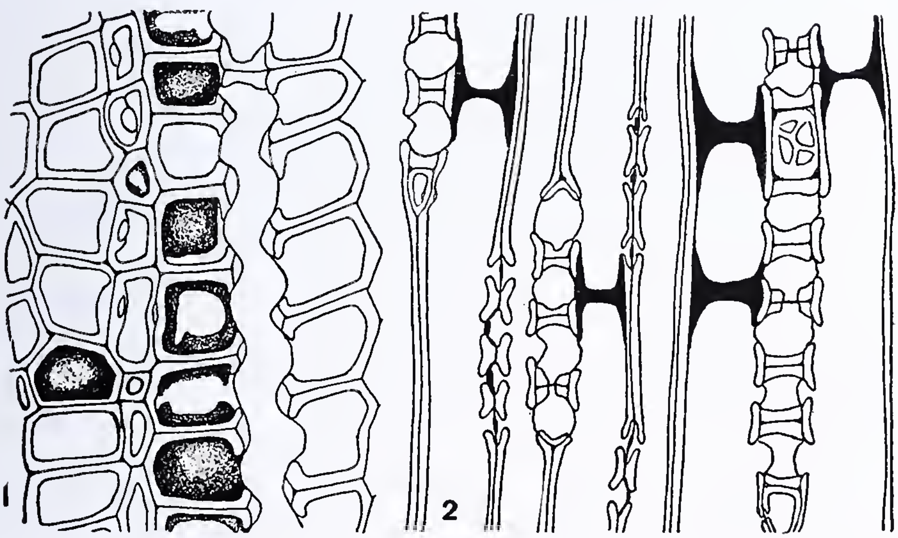


FIG. 14. — Resin plates in *Pinus albicaulis*. (1) Cross section, showing a row of tracheids with resin plates opposite the large pits of the ray cells. (2) Tangential section, showing five spool-shaped resin plates opposite the rays.

plates across them. Such plates are common in various woods and are characteristic of the Araucariaceae, in the latter case being always associated with the rays. They are thinner at the center than at the sides and, in longitudinal sections of the wood, re-

semble trabeculae, except for their darker color (Fig. 14). Tracheids with resin plates are sometimes called *resinous tracheids.*

In response to gravity or other stimulus, the under side of the woody cylinder of branches and leaning or crooked stems of Gymnosperms is commonly reinforced by layers of dense, reddish or yellowish brown wood, known as *Rothholz* or *compression wood,* which appear in cross section as successive lunes resembling locally thickened segments of normal late wood (Fig. 15). The tracheids

Fig. 15. — Cross section of *Picea*, showing dark-colored layers of Rothholz. Slightly reduced. (Photo by U. S. Forest Service.)

are characterized by a thick, heavily lignified, spirally striate inner layer of the secondary wall,* and in the main part of such a layer there are interstitial spaces between the rounded corners of the tracheids. In response to changes in the moisture content the tissue shrinks and swells excessively, not only laterally but also longitudinally, thus differing from normal wood which shrinks very little lengthwise.

Strand tracheids, sometimes (inappropriately) termed *septate tracheids,* are found in the stems of certain Gymnosperms, mostly

* When cross sections of these cells are examined under the high power of a compound microscope, the slightest change in focus of the instrument will impart an illusory rotary motion to the spirally striate inner layers.

in the immediate vicinity of wounds and vertical resin ducts. They develop in the same manner as the cells of a parenchyma strand, *i.e.*, by the transverse segmentation of a mother cell, and may occur with parenchyma cells in *mixed strands.* Occasionally these mixed strands are terminal, *i.e.*, on the outer face of the late wood, in *Picea, Pseudotsuga,* and *Larix.**

All the ordinary tracheids of Gymnosperms serve both as conductive and strengthening elements, though in the thick-walled cells of late wood the mechanical function is emphasized. In the Dicotyledons there is a greater variety of cell forms, and the division of labor among them is more pronounced. The tracheary function is mostly performed by tube-like cell-fusions (vessels), and the mechanical mostly by fibrous cells (wood fibers) whose conductive activity is reduced, sometimes seemingly almost to the vanishing point.

Dicotyledonous tracheids are of three types, namely, *vasicentric tracheids,* short forms about vessels; *vascular tracheids,* resembling the members of small vessels; and *fiber-tracheids,* or wood fibers with bordered pits. The first two types differ in many ways from the ordinary tracheids of Gymnosperms, being much shorter and fewer, rarely arranged in radial rows, and having numerous small bordered pits in all facets of their walls.

Vasicentric tracheids are short and irregularly formed tracheids in the immediate proximity of large vessels (*e.g., Quercus, Castanea, Eucalyptus* spp.). They are not in definite vertical rows or series, and usually are flattened by the pressure of the expanding vessel, sometimes being partially disjoined laterally, thus becoming **disjunctive tracheids.**

Vascular tracheids are imperfect or degenerate members of a vessel. A vertical series of them is like a small vessel in every way except that there are no open passages (perforations) connecting the cavities of the superposed cells. In the late wood of some Dicotyledons series of vascular tracheids replace vessels in the late wood. Their inner walls may be spirally thickened.

Wood fibers of Dicotyledons are typically attenuated xylem cells that, as a result of gliding growth during differentiation, are much longer than the cambial initials from which they were derived. In some kinds of woods the fiber pits are distinctly bor-

* See *Botanical Gazette* 48: 47–55, July 1909.

dered and in some other kinds they are obviously simple, but between the two extremes are intermediate stages of reduction where it is difficult to decide whether the pits are simple or retain vestigial borders. Sometimes fibers with simple pits are associated with others in which the pit border is clearly differentiated. Wood fibers with bordered pits are called **fiber-tracheids,** and those with simple pits, **libriform fibers.**

A **fiber-tracheid** is typically a wood cell with a thick secondary wall, pointed ends, and small bordered pits having lenticular to slit-like, usually extended, inner apertures. Those most resembling ordinary tracheids characterize the more primitive dicotyledonous woods, tend to form definite radial rows (Plate VI, Fig. 1), and are associated with heterogeneous rays and small, scalariformly perforated vessel members. Spiral thickenings are present in the fiber-tracheids of some woods (*e.g.*, certain species of *Ilex, Euonymus, Symplocos*).

In wood fibers with simple or reduced bordered pits the protoplast may divide after the completion of the secondary wall. The result is the formation of two or more cells within the lumen of the fiber. The walls of these internal cells usually remain very thin and unpitted, but sometimes secondary walls develop, producing a well-defined series of cells within another cell. The division walls are transverse, extending only to the inner surface of the fiber wall, and appear as septa partitioning the fiber lumen. These chambered fibers are termed **septate wood fibers.** They are of fairly common occurrence in tropical woods (*e.g., Swietenia*). Septate fibers serve for storage of starch in sapwood and may contain numerous crystals of calcium oxalate in heartwood. In some of the Polygonaceae, such crystalliferous fibers occur in concentric, parenchyma-like bands visible to the unaided eye; in some of the Lecythidaceae they are common at the margins of the parenchyma layers.

Fiber-tracheids are sometimes *falsely septate* owing to the presence of thin transverse plates of a resinous or gummy nature. These plates originate in the same manner as those in the so-called resinous tracheids of Gymnosperms. Libriform fibers and fiber-tracheids with very thick walls frequently have layers that contract excessively in drying. Such cells are usually termed **gelatinous fibers.** In *Robinia* and *Toxylon* gelatinous fibers constitute

rather large horn-like masses in the late wood, separated by groups or bands of parenchyma and small vessels.

Wood fibers vary greatly in size, shape, thickness of wall, and in the nature and distribution of the pits. In woods with storied structure they taper to a point at each end from a fairly definite enlarged middle part that corresponds in length to that of the cambial initial; transition may be gradual or abrupt, and in the latter case there may be aggregates of small simple pits at the "shoulders." In cross sections of such woods the fibers are likely, therefore, to appear as being of two distinct sizes.

In *Ulmus* the fibers are in irregular layers alternating with zones of small vessels (Plate III, Fig. 2). Some woods, especially of tropical origin, are composed of alternate laminae of fibers and of parenchyma. The proportion of wood fibers to other elements and the thickness of the walls may vary widely in different parts of the same tree, especially if the woods are ring-porous. Growth rings may be demarcated by one to several rows of distinctly flattened fibers.

During the process of elongation the tips of the wood fibers glide along and between adjacent cells. When a tip meets a ray it may stop abruptly or become forked or bend along the margin or penetrate between the cells, but more commonly it passes to one side. The serrations often observed on one side of a fiber tip are the impressions of the lateral walls of ray cells with which the fiber was in contact.

There are special short forms of wood cells in Dicotyledons which belong in the general category of wood fibers, although they bear considerable resemblance to fusiform wood parenchyma cells. They are little if any longer than their cambial initials and have thin walls and simple pits. They are characteristic of woods exceptionally light in weight (Fig. 41).

TABLE III

Length of Tracheids in Fifty Gymnosperms

(From Bailey and Tupper, *Proc. Am. Acad. Arts and Sci.* 54: 2: 155–162)

Botanical Name	Age years	Maximum mm.	Mean mm.	Minimum mm.
Abies concolor	20–60	4.0	2.5	0.7
lasiocarpa	20–60	2.7	2.4	1.3
nobilis	60+	5.4	4.4	3.5
Agathis australis	60+	7.3	5.4	3.3
robusta	60+	8.2	7.1	4.1
Araucaria brasiliensis	60+	9.4	6.6	2.3
Cunninghamii	60+	10.9	6.2	2.5
imbricata	20–60	4.7	3.5	2.2
Callitris calcarata	60+	5.5	2.7	1.9
Cedrus Libani	60+	4.0	3.0	2.0
Chamaecyparis Lawsoniana	60+	4.1	3.4	2.7
thyoides	20–60	4.7	3.8	2.9
Cryptomeria japonica	60+	3.7	2.7	1.9
Cupressus arizonica	20–60	2.1	1.5	1.1
macrocarpa	20–60	3.8	3.2	2.8
Dacrydium Franklinii	60+	2.4	1.9	1.5
Dioon spinulosum	60+	9.5	6.8	4.1
Gingko biloba	60+	4.8	3.5	2.8
Juniperus bermudiana	20–60	3.7	2.3	1.4
virginiana	20–60	2.8	2.0	1.3
Keteleeria Davidiana	60+	5.6	4.7	2.2
Larix decidua	20–60	4.9	4.0	3.3
occidentalis	60+	5.6	4.4	1.9
Libocedrus decurrens	20–60	3.8	3.2	2.7
Picea glauca	20–60	4.1	3.4	2.9
excelsa	20–60	2.4	1.9	1.5
rubens	60+	3.2	2.6	1.6
sitchensis	20–60	6.8	5.6	4.5
Pinus cembra	60+	2.6	2.0	1.2
Lambertiana	60+	5.5	4.4	2.7
Merkusii	20–60	6.9	5.2	3.5
monticola	60+	6.0	5.2	3.9
ponderosa	60+	3.8	3.3	2.2
rigida	60+	5.3	4.0	3.2
strobus	20–60	5.0	3.9	2.3
taeda	20–60	7.3	5.4	3.6
Podocarpus chinensis	60+	3.7	2.5	1.2
elata	60+	4.8	3.3	1.7
latifolia	60+	6.5	5.1	2.6
Pseudotsuga taxifolia	20–60	4.2	2.6	1.8
Sciadopitys verticillata	60+	3.8	3.2	2.5
Sequoia sempervirens	20–60	9.2	6.4	2.6
Taiwania cryptomerioides	20–60	6.7	5.7	5.1
Taxodium distichum	60+	7.8	6.5	3.5
Taxus baccata	20–60	3.1	2.5	2.2
brevifolia	20–60	2.1	1.7	0.7
Thuja occidentalis	20–60	2.9	2.2	1.3
plicata	60+	4.0	3.2	2.0
Torreya nucifera	60+	4.3	3.2	2.2
Tsuga canadensis	20–60	4.3	3.2	1.9

TABLE IV

Length of Wood Fibers and of Vessel Members in Fifty Dicotyledons
(From Bailey and Tupper, *Proc. Am. Acad. Arts. and Sci.* 54: 2: 165–180)

Botanical Name	Age years	Wood fibers			Vessel members
		Maximum mm.	Minimum mm.	Mean mm.	Mean mm.
Acer saccharinum	30+	0.8	0.5	0.6	0.4
Aesculus glabra	30+	1.1	0.7	0.9	0.4
Altingia excelsa	30+	3.1	2.0	2.8	1.9
Aporosa symplocosifolia	15–30	2.9	1.3	2.1	0.9
Aralia spinosa	15–30	1.0	0.5	0.7	0.4
Baccharis halimifolia	15–30	0.7	0.3	0.5	0.2
Betula lutea	30+	2.1	1.1	1.7	1.2
Bruguiera gymnorrhiza	15–30	2.1	1.3	1.7	1.0
Bursera Simaruba	15–30	1.3	0.6	1.0	0.5
Castanea vesca	30+	1.2	0.7	1.0	0.7
Casuarina torulosa	30+	1.4	0.7	1.0	0.6
Cercidiphyllum japonicum	30+	2.2	1.4	1.9	1.6
Cercis canadensis	30+	1.4	0.7	1.0	0.2
Cordia Gerascanthus	15–30	2.0	1.4	1.7	0.3
Cornus florida	30+	2.0	1.4	1.7	1.1
Crataeva tapia	15–30	1.0	0.7	0.8	0.3
Curatella americana	15–30	2.4	1.4	2.1	0.7
Diospyros virginiana	30+	1.3	0.8	1.0	0.4
Drimys Winteri	30+	5.1	3.5	4.3	...
Eucalyptus rostrata	15–30	0.8	0.5	0.7	0.3
Fagus grandifolia	30+	1.4	0.9	1.2	0.6
Fraxinus americana	30+	1.2	0.7	0.8	0.3
Grevillea robusta	15–30	2.1	1.0	1.6	0.4
Guaiacum officinale	30+	0.7	0.3	0.5	0.1
Hicoria ovata	30+	1.5	0.8	1.1	0.5
Hopea acuminata	30+	1.9	1.0	1.5	0.4
Ilex opaca	30+	1.8	0.9	1.3	0.9
Lagerstroemia reginae	15–30	1.5	0.6	1.2	0.4
Liriodendron tulipifera	30+	2.8	1.7	2.3	1.1
Magnolia acuminata	30+	2.1	0.9	1.6	0.8
Morus alba	15–30	1.2	0.7	0.8	0.2
Myrica californica	15–30	1.3	0.8	1.0	0.7
Nyssa aquatica	15–30	1.7	1.2	1.4	1.1
Ochroma lagopus	30+	1.4	0.7	1.0	0.4
Pisonia obtusata	30+	0.8	0.4	0.6	0.1
Platanus occidentalis	30+	1.9	1.0	1.6	0.5
Populus grandidentata	15–30	1.5	1.0	1.3	0.7
Prunus serotina	30+	1.8	1.1	1.4	0.5
Sassafras variifolium	30+	1.1	0.7	0.8	0.4
Simaruba glauca	30+	1.1	0.7	1.0	0.6
Spondias mangifera	30+	1.4	0.7	1.0	0.5
Suaeda fruticosa	15–30	0.4	0.2	0.3	0.1
Swietenia mahagoni	15–30	1.3	0.7	1.0	0.4
Symphonia globulifera	15–30	1.9	1.4	1.7	0.6
Tabebuia pentaphylla	15–30	1.1	0.7	0.9	0.3
Thea japonica	30+	2.0	1.0	1.7	0.7
Tilia americana	30+	1.5	0.8	1.1	0.4
Trochodendron aralioides	30+	6.0	2.8	4.5	...
Ulmus americana	30+	1.3	0.8	1.1	0.2
Viburnum lentago	30+	1.8	1.2	1.5	1.0

TABLE V

Type of Fiber Pitting in Certain Dicotyledonous Woods

Genus	Simple	Bordered	Genus	Simple	Bordered
Acacia	X		Juglans		X
Acer		X	Kalmia		X
Aesculus		← X	Leitneria	X	
Ailanthus (Nat.)	X		Liquidambar		X
Alnus		X	Liriodendron		X
Amelanchier		X	Magnolia		X
Amyris		← X	Melia	X	
Andromeda		X	Mohrodendron		X
Anona	X		Morus	X	
Arbutus	X →		Myrica		X
Arctostaphylos	X →		Nyssa		← X
Asimina	X		Ocotea	X	
Avicennia	X		Olneya	X	
Betula		X	Ostrya		X
Broussonetia (Nat.)	X		Oxydendrum		X
Bumelia	X		Parkinsonia	X	
Bursera	X		Paulownia (Nat.)	X	
Carpinus		X	Persea	X	
Castanea		X	Planera	X	
Castanopsis		X	Platanus		X
Catalpa	X		Populus	X	
Ceanothus	X		Prosopis	X	
Celtis	X		Prunus		X
Cercis	X		Ptelea	X	
Cercocarpus	X		Pyrus		X
Chilopsis	X		Quercus		X
Chionanthus		X	Rhamnus	X	
Chrysophyllum	X →		Rhizophora	X	
Cladrastis	X		Rhododendron		X
Cornus		X	Rhus	X	
Cotinus	X		Robinia	X	
Crataegus		X	Salix	X	
Cyrilla		X	Sambucus	X	
Diospyros		X	Sapindus	X	
Eucalyptus (Int.)		X	Sassafras	X	
Fagus		X	Sideroxylon	X	
Ficus	X		Swietenia	X	
Fraxinus	X →		Symplocos		X
Fremontodendron	X		Tilia		← X
Gleditsia	X		Toxylon	X	
Gordonia		X	Ulmus	X	
Guaiacum		X	Umbellularia	X	
Gymnocladus	X		Vaccinium		X
Hamamelis		X	Viburnum		X
Hicoria (Carya)		X	Xanthoxylum	X	
Ilex		X			

Arrows indicate transitions from the prevailing type.

Vessels

Vessels are cell-fusions serving as tubes for the conduction of water. They characterize the secondary woods of all Angiosperms except *Drimys*, *Tetracentron*, *Trochodendron*, and *Zygogynum*, and are absent from all the Gymnosperms except the three atypical genera *Ephedra*, *Gnetum*, and *Welwitschia*.

The principal stages in the formation of a vessel are as follows: Mother cells in an indeterminate vertical row give rise simultaneously to a corresponding series of tracheid-like cells; each of the latter increases in diameter, sometimes enormously, but ordinarily not in length, and then develops its secondary wall in the usual manner; this is followed by the disappearance of the protoplast as in an ordinary tracheid, except that immediately preceding the loss of the cell contents, perforations appear in the walls and connect the cavities so that transmission can take place directly from cell to cell instead of through pit membranes. It is to the resulting compound structure that the term *vessel* is properly applied. One of the perforated cellular components of a vessel is termed a **vessel member** or a **vessel element.***

Perforations are formed by the absorption of the membranes of complementary pits, which may be simple, bordered, or partially bordered, and either of an ordinary or a special form. For convenience in describing the different types of perforations, the area of cell wall directly involved in their formation (but not including any permanent pits) has been designated the **perforation plate.**† A typical vessel member has two plates in opposite walls, usually located at or near the ends, and, like pits, each plate has a complement.

A group of elongated and parallel openings, together with the parts of the wall surrounding and separating them, constitute a **scalariform perforation plate**‡ (Fig. 16, No. 2; 17, No. 2). The

* Further use of the term *segment* (from the Latin *secare*, to cut off) should be discouraged, since it implies the reverse of the actual process of vessel formation.

† This term is not really analogous to *sieve plate* in phloem. One difference is that a sieve plate is a definite region, whereas the boundary of a perforation plate often is indefinite.

‡ The term *scalariform perforation*, now in common use, is obviously wrong unless the individual openings in a group are regarded as subdivisions of a single large perforation. This would imply that the scalariform type, characteristic of primitive plants, had evolved from a single large opening such as is

remnants of the plate between the perforations are called **bars.** The number, thickness, form, and spacing of the bars provide features of considerable diagnostic value. There are various modifications of scalariform plates, and the bars may appear

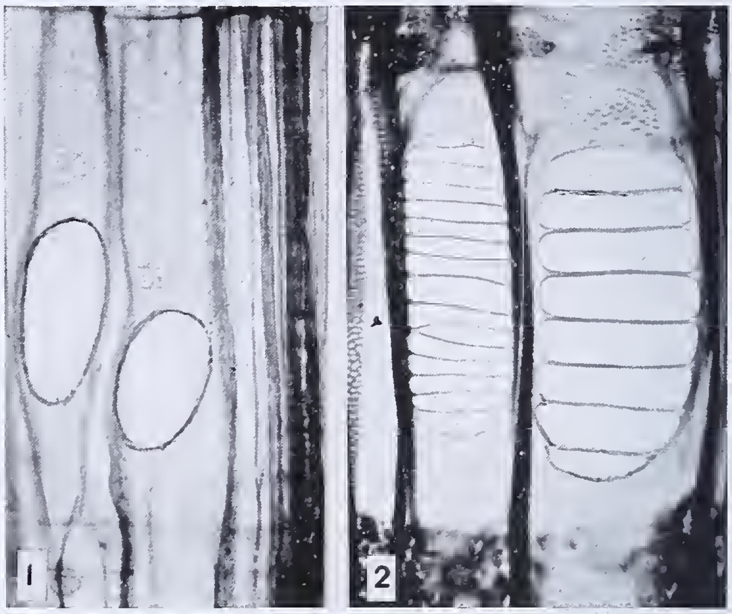


Fig. 16. — Simple and multiple perforations in vessel members. ×250. (1) Two simple perforations in *Populus tremuloides* (Aspen). (2) Two scalariform perforation plates with narrow bars in *Betula nigra* (River Birch). Note the difference in the number and spacing of the bars in adjacent vessel members. (Photomicrographs by U. S. Forest Service.)

branched or reticulated. Sometimes (*e.g.*, certain Myristicaceae) each of the elongated perforations of one member conforms to a group of smaller openings in the contiguous member. Scalariform plates are characteristic of long, overlapping vessel members and therefore are nearly always more or less steeply inclined, facing the rays.

In a few tropical woods (*e.g.*, certain Bignoniaceae, Boraginaceae, and Nyctaginaceae) the plates are transverse, with numerous small rounded or polygonal perforations producing foraminate (Fig. 17, No. 4) or reticulate patterns, respectively. In *Ephedra* (order Gnetales) the plates are oblique and foraminate, the per-

---

found in more highly specialized plants. It is correct to say that vessel members are scalariformly perforated.

forations being of the same size as the pit membranes of the larger bordered pits from which they obviously have been derived (Fig. 17, No. 3). In *Gnetum* the plates are oblique and, while some are foraminate, most of them have a single large opening; there are also transitional forms.

With evolutionary increase in specialization of the elements of wood, the vessel members tend to lose their resemblance to tracheids and to become shorter and relatively wider, the ends blunter, and the shape in cross section less angular. As the perforation plates become less oblique and ultimately transverse, the perforations, which were narrow and scalariformly arranged in the lateral walls, tend to coalesce into a single, large, oval or circular opening, termed a **simple perforation*** (Fig. 16, No. 1; 17, No. 1). There are concomitant changes in the cells of the surrounding tissues, particularly in the wood fibers, which become less tracheid-like in various ways, including the gradual disappearance of the borders from their pits.

Simple perforations are of more common occurrence than any other type, and frequently characterize entire families (see Table VI). Woods with storied structure have simple perforations exclusively. In woods with vessels of two distinct sizes, the members with large lumina have only simple perforations, whereas some or all of the small ones may have scalariform perforation plates, though usually with few bars. Both types of perforations may occur together in woods with vessels all of approximately the same size (*e.g.*, *Platanus*, Myristicaceae in part), though usually one or the other predominates. Not infrequently the members of vessels adjacent to the primary xylem are scalariformly perforated, while those situated further out have simple perforations (*e.g.*, *Magnolia acuminata*).

When its plate is oblique, a simple perforation is oval, with its shortest axis horizontal, and the remnant of the plate surrounding it, called the **perforation rim** (Fig. 17, No. 1), is comparatively wide. In large vessel members that abut squarely on one another the perforation rim (formerly called the *annular ridge*) may vary from moderately wide to exceedingly narrow.

The course of a vessel is generally parallel to that of the other axially elongated elements, but it may deviate more or less sharply

* *Simple* is here used in the sense of *solitary* and not as the opposite of *compound.*

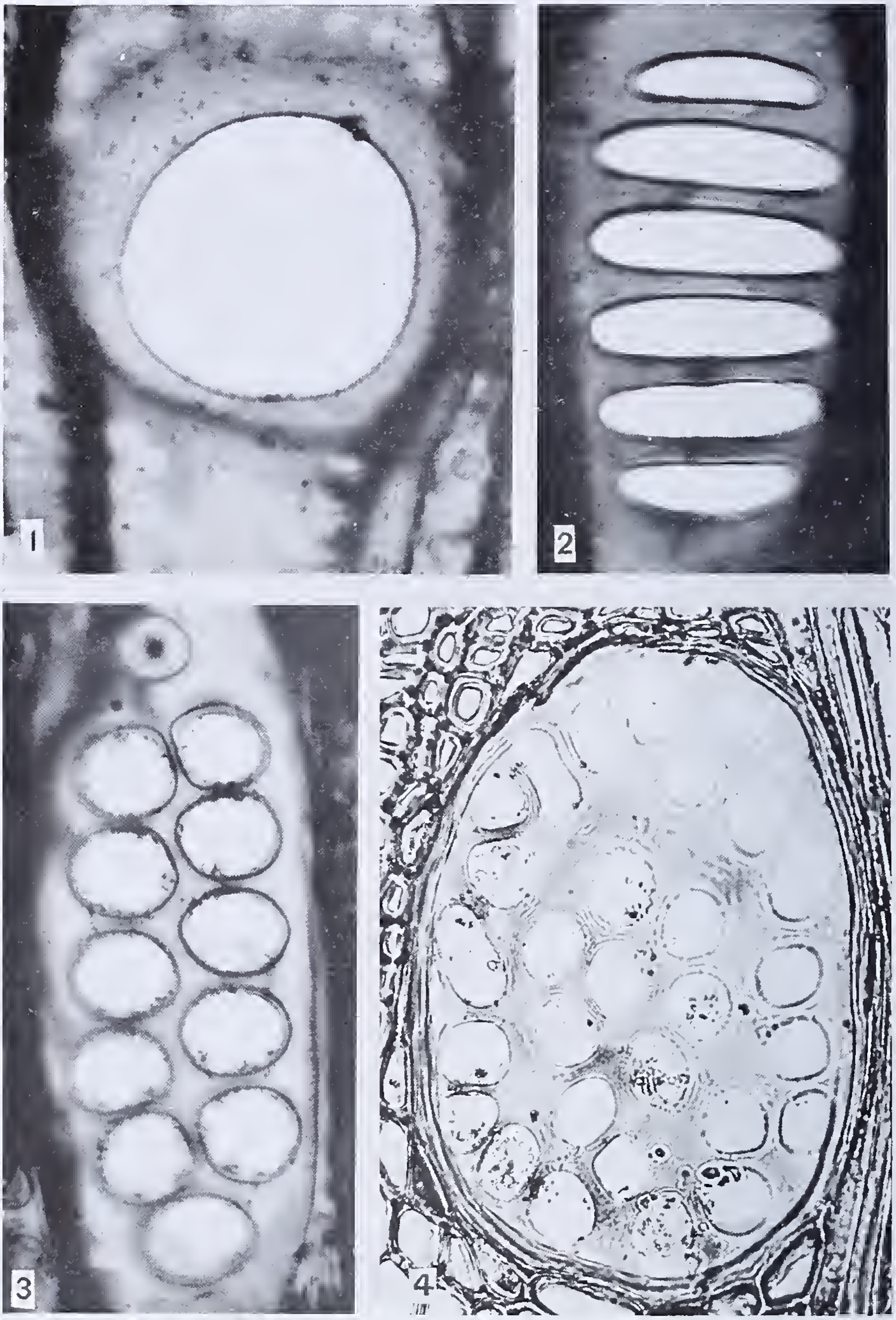


FIG. 17. — Simple and multiple perforations in vessel members. (1) Simple perforation in *Eriodictyon crassifolium*. The encircling area is the perforation rim. ×890. (2) Scalariform perforation plate with heavy bars in *Ceriops Roxburghiana*. ×890. (3) Foraminate perforation plate in *Ephedra alta*. ×890. (4) Foraminate perforation plate in *Dolichandrone platycalyx*. ×400. (Last photomicrograph by L. Chalk.)

to the right or left in the tangential plane. This occurs when the successive members arise from mother cells in diagonal rather than the usual vertical series. Sometimes four or five members develop in a nearly horizontal tangential row (Fig. 19, No. 2), in which case the simple perforations are situated in the radial walls. Such an arrangement of the elements of a single vessel has the appearance on cross section of a tangential row of vessels. Sometimes the course of a vessel changes from one side of a high and narrow ray to the other by means of special connective ray cells, which may be either simply or scalariformly perforated.* Vessels occasionally branch and coalesce.

The form of a vessel member is seen to best advantage in macerated preparations. Members with transverse perforation plates are cylindrical or more or less barrel-shaped (Fig. 19, No. 1). Those with oblique plates are rather uniformly cylindrical or prismatic between the plates, and diminish gradually or abruptly toward the ends. A plate may extend to the end of a cell or there may be a short to long ligulate projection beyond it. The forms of these tips are often distinctive, but they exhibit considerable variation in the same specimen and even in the same vessel.

Spiral thickenings of the secondary wall characterize some vessels (Fig. 18), but they are much less common in tropical woods than in those of the temperate zones. They are usually absent from large vessels even when present in the small ones of the same specimen. Sometimes (*e.g.*, Hamamelidaceae and certain Ericales) spirals are confined to the ligulate extensions of a member beyond the perforation plates. Trabeculae are of sporadic occurrence, but are without diagnostic value.

The nature of the pitting in different facets of the wall of a vessel depends largely upon the type of adjoining cells; if the complementary pits are simple, the pits in the vessel may be simple, bordered, or partially bordered, frequently varying in the same cross-field. Intervascular pitting usually is seen to best advantage in the tangential section.

As vessels cease to function actively, their cavities frequently become more or less completely filled with excretions from adjacent ray and wood parenchyma tissue. Deposits of a gummy nature

---

* See Chalk, L., and M. M. Chattaway: Perforated ray cells. *Proc. Roy. Soc.* 13: 113: 82–92. 1933.

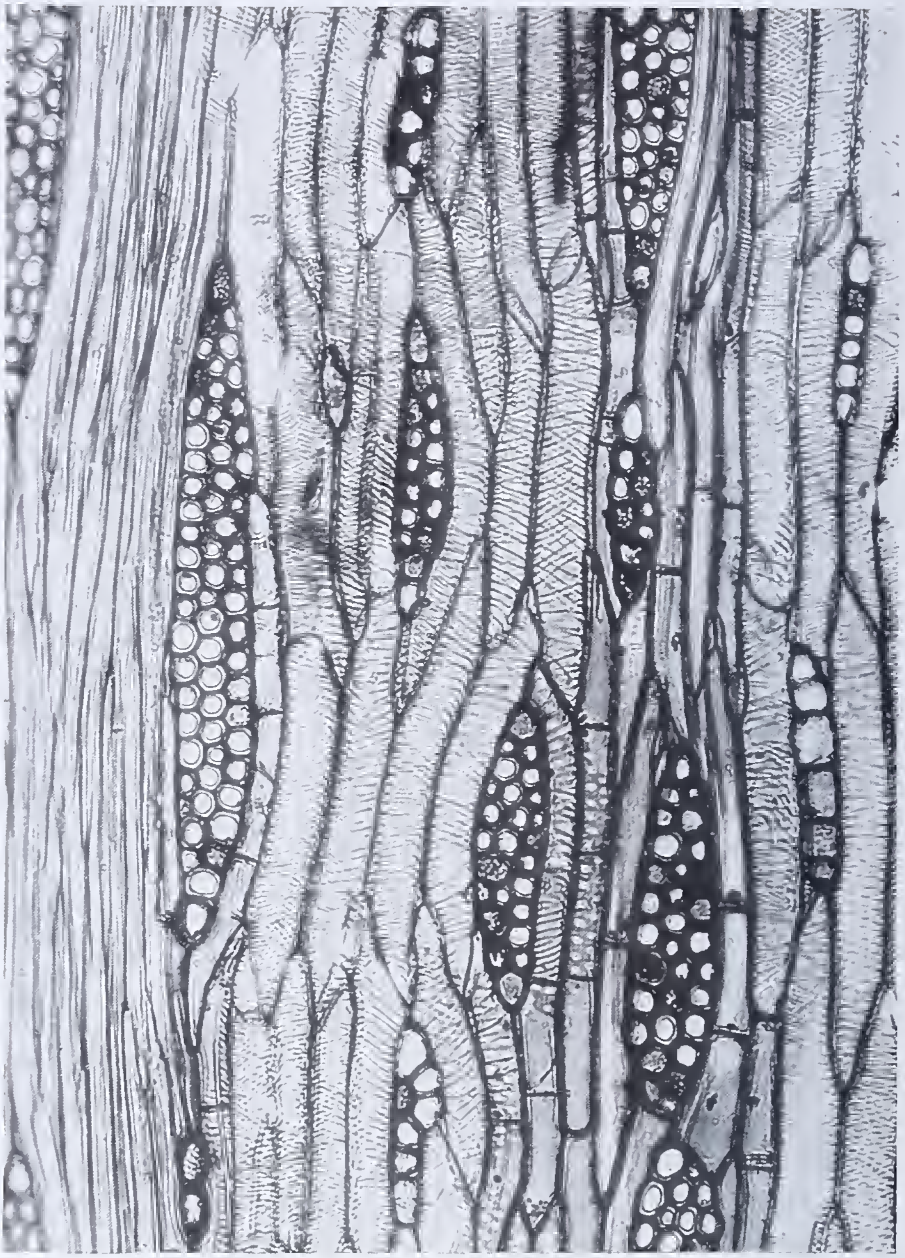


Fig. 18. — Tangential section of *Ulmus americana* (White Elm), showing members of small vessels with spiral thickenings. At the left is a layer of libriform fibers, and to the right of the middle are several wood parenchyma strands. ×250. (Photomicrograph by U. S. Forest Service.)

are common (*e.g.*, Leguminosae) either in large, irregular masses, or in thick plates lodged against the perforation rims (*e.g.*, Meliaceae, *Prunus serotina*), or as thin, unevenly spaced septa (*e.g.*, *Nyssa sylvatica*). Deposits of calcium carbonate are normally present in a few species (mostly Ulmaceae) and are likely to appear traumatically in any dicotyledonous wood.* Parenchymatous intrusions (see *Tyloses*) are common in the heartwood and inner sapwood of many species.

A cross section of a vessel member (and also of a vascular tracheid) is conveniently referred to as a **pore.**† If the plane of section is through the overlapping ends of two members the result will be two tangentially arranged pores of the same vessel. Sometimes, as previously explained, a tangential row of four or five pores may represent only one vessel (Fig. 19, No. 2). The diameter of a vessel may be fairly uniform throughout its course, but if its members taper at the ends, the size and shape of the pores in successive sections will exhibit considerable variation. The thickness of the secondary wall varies greatly in different woods, and sometimes in different parts of a growth ring, or even in different facets of the same cell (*e.g.*, *Hicoria*, *Diospyros*).

The size, form, and relative number of pores, and their arrangement with relation to one another and to the other elements, especially parenchyma, are often highly distinctive. Woods in which the pores are of fairly uniform size and distribution or undergo only gradual changes in these respects during the growth of a season are referred to as **diffuse-porous** (*e.g.*, *Acer*, *Betula*, *Liriodendron*); and those in which the pores of the inner part of each growth ring exhibit decided contrast in size or number (or both) to those of the outer part, as **ring-porous** (*e.g.*, *Castanea*, *Fraxinus*, *Robinia*). The two types intergrade. Certain woods (*e.g.*, *Juglans nigra*) are normally intermediates, and some kinds (*e.g.*, *Tectona*, *Prosopis juliflora*) are ring-porous when grown in one region and diffuse-porous when produced in a different environment. In the same specimen, layers with well-developed late

---

* See *Tropical Woods* 12: 22–26. 1927.

† It should be noted that the term *pore* applies to a vessel member rather than to the vessel as a whole, and that it is not limited to the cell cavity, but includes the wall also. Vascular tracheids are placed in the same category as vessel members because ordinarily the only distinguishing feature (absence or presence of perforations) cannot be detected in cross sections.

wood may be distinctly ring-porous, whereas other layers in which growth was slow may be composed almost entirely of early wood and so appear diffuse-porous. Comparatively few woods are ring-

FIG. 19. — Vertically and tangentially alined members of a vessel. (1) Tangential section of *Diospyros virginiana* (Persimmon), showing three vessel members in normal vertical alinement. (2) Tangential section of *Capparis verrucosa*, showing four vessel members in lateral alinement where the vessel abruptly changes its course. A cross section through the middle of these members would show four pores of a single vessel.

porous and nearly all of them are found in the north temperate zone.

Pores vary from minute and scarcely distinct with a lens to large and readily visible to the unaided eye. They may be few to numerous, crowded to widely spaced, uniformly to very unevenly distributed. If they are not too numerous and crowded, four fairly distinct types of occurrence are usually recognizable, namely, (*a*) *solitary*, (*b*) in *multiples*, (*c*) in *chains*, and (*d*) in *clusters*. The last three terms are chiefly for convenience in referring to

the appearance of the pores to the unaided eye or at low magnification.

Solitary pores (Fig. 27) are of common occurrence with other forms, but it is unusual for all the pores in a section to be isolated. They are usually circular or oval, in the latter case with the longest axis normally radial. A **pore multiple** (Fig. 27) is a group of pores that are crowded together and so flattened along the lines of contact that they appear as subdivisions of a single pore. The number in a group varies from two to several or many, but the commonest forms, especially when associated with solitary pores, are radial pairs or threes. A **pore chain** (Fig. 20) is a series or line

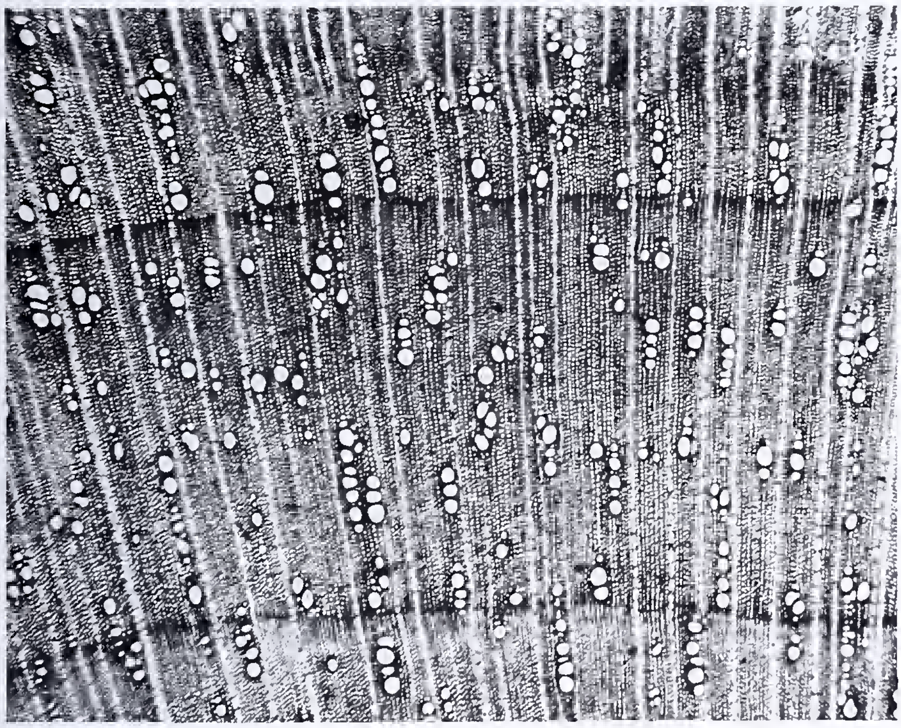


FIG. 20. — Pore chains in *Capparis tenuisiliqua*. ×40.

of pores that are very close together and when in contact with one another preserve their separate identities. The lines are generally radial, but may be tangential or oblique. A **pore cluster** (Fig. 21) is a small to large, rounded or irregular, more or less isolated group of pores, frequently surrounded by parenchyma.

Various combinations and multiplications of the foregoing types give rise to a great variety of pore patterns. Solitary pores and

small multiples may exhibit a fairly definite radial, diagonal, or tangential alinement. Pore chains sometimes occur successively in long radial or oblique series. Pore clusters may be confluent and form short to long oblique or irregular concentric bands that are continuous except for interruptions of the rays (Plate III, Fig. 2). The arrangement of pores is often controlled by the rays,

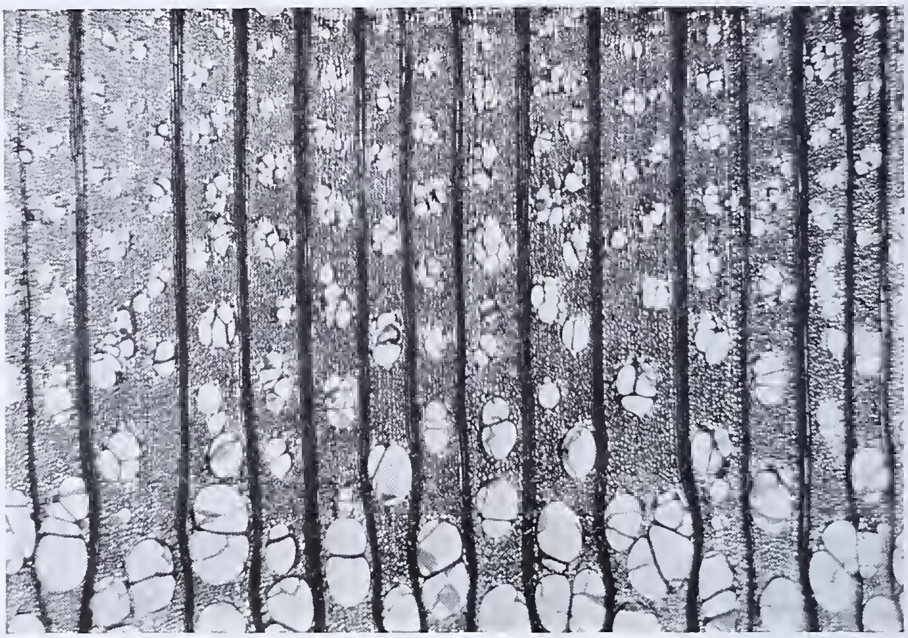


FIG. 21. — Pore clusters in *Morus rubra* (Red Mulberry). The small pores in the late wood are mostly in clusters; the large pores in the early wood are in multiples. ×25.

particularly when the rays are close together or very large. Some of the most conspicuous patterns involve a combination of pores and other elements, especially parenchyma (Frontispiece). Pore patterns provide one of the most useful features in identifying woods, but allowance should be made for local variations and the effect of rate of growth.

TABLE VI

Families Characterized by Simple Perforations in the Vessels

(Asterisk indicates tendency to multiple perforations)

Acanthaceae	Dichapetalaceae*	Myoporaceae
Aceraceae	Dipterocarpaceae	Myrsinaceae*
Actinidiaceae*	Ebenaceae	Myrtaceae
Akaniaceae*	Elaeagnaceae	Nyctaginaceae*
Alangiaceae*	Elaeocarpaceae*	Ochnaceae*
Amarantaceae	Ephedraceae	Olacaceae*
Amygdalaceae	Erythroxylaceae*	Oleaceae*
Anacardiaceae*	Euphorbiaceae*	Oliniaceae
Anonaceae	Eupomatiaceae	Onagraceae*
Apocynaceae	Fagaceae*	Opiliaceae
Araliaceae*	Flacourtiaceae*	Oxalidaceae
Aristolochiaceae	Fouquieriaceae*	Pandaceae*
Asclepiadaceae	Geraniaceae	Papaveraceae
Avicenniaceae	Gesneriaceae	Passifloraceae*
Berberidaceae*	Gnetaceae	Phytolaccaceae
Bignoniaceae	Gonystylaceae	Pittosporaceae
Bombacaceae	Goodeniaceae	Platanaceae*
Boraginaceae	Greyiaceae	Plumbaginaceae
Bretschneideraceae	Guttiferae	Polygalaceae
Brunelliaceae*	Hernandiaceae*	Polygonaceae
Burseraceae	Hippocastanaceae	Portulacaceae
Cactaceae	Hippocrateaceae*	Proteaceae
Calycanthaceae	Hydrophyllaceae	Quiinaceae
Campanulaceae*	Hypericaceae	Ranunculaceae
Capparidaceae	Juglandaceae*	Rhamnaceae
Caricaceae	Koeberliniaceae	Rosaceae*
Caryocaraceae*	Krameriaceae	Rubiaceae*
Casuarinaceae*	Lauraceae*	Rutaceae*
Celastraceae*	Lecythidaceae	Salicaceae
Chenopodiaceae	Leguminosae	Salvadoraceae
Cistaceae	Leitneriaceae	Santalaceae
Cneoraceae	Linaceae	Sapindaceae
Cochlospermaceae*	Loganiaceae*	Sapotaceae*
Combretaceae	Loranthaceae	Sarcospermaceae
Commelinaceae	Lythraceae	Scrophulariaceae
Compositae	Malpighiaceae	Simarubaceae
Connaraceae	Malvaceae	Solanaceae
Convolvulaceae	Marcgraviaceae*	Sonneratiaceae
Coriariaceae	Melastomaceae	Sterculiaceae
Crassulaceae	Meliaceae	Surianaceae
Cruciferae	Melianthaceae	Tamaricaceae
Crypteroniaceae	Menispermaceae	Theophrastaceae
Cucurbitaceae	Menthaceae	Thymelaeaceae
Datiscaceae	Moraceae	Tiliaceae

TABLE VI — (Continued)

Trigoniaceae	Umbelliferae*	Vitaceae*
Triplochitonaceae	Urticaceae	Vochysiaceae
Turneraceae*	Valerianaceae*	Welwitschiaceae
Ulmaceae*	Verbenaceae*	Zygophyllaceae

TABLE VII

FAMILIES CHARACTERIZED BY SCALARIFORM PERFORATION PLATES IN THE VESSELS

(Asterisk indicates tendency to simple perforations)

Aquifoliaceae	Ericaceae*	Myrothamnaceae
Betulaceae	Escalloniaceae	Nyssaceae
Bixaceae*	Eucommiaceae*	Ocktoknemataceae
Buxaceae*	Eucryphiaceae	Piperaceae*
Canellaceae	Eupteleaceae	Platanaceae*
Caprifoliaceae*	Garryaceae	Rhizophoraceae*
Cercidiphyllaceae	Grossulariaceae	Sabiaceae
Chloranthaceae	Hamamelidaceae	Saurauiaceae*
Clethraceae*	Himantandraceae*	Scytopetalaceae
Columelliaceae	Humiriaceae	Stachyuraceae
Cornaceae*	Hydrangeaceae	Staphyleaceae*
Corylaceae*	Icacinaceae*	Styracaceae
Crossosomataceae*	Lacistemaceae	Symplocaceae
Cunoniaceae*	Magnoliaceae*	Theaceae*
Cyrillaceae	Monimiaceae*	Vacciniaceae*
Dilleniaceae*	Myricaceae*	Violaceae*
Epacridaceae*	Myristicaceae*	

TABLE VIII

North American Woods with Spiral Thickenings in Some or All of the Vessels

Aceraceae	Ericaceae (Cont.)	Oleaceae
Acer	Oxydendrum	Chionanthus
Amygdalaceae	Rhododendron	Osmanthus
Prunus	Hamamelidaceae	Rhamnaceae
Anacardiaceae	Hamamelis	Ceanothus
Cotinus	Liquidambar	Rhamnus
Rhus	Hippocastanaceae	Rosaceae
Anonaceae	Aesculus	Amelanchier
Asimina	Koeberliniaceae	Aronia
Aquifoliaceae	Koeberlinia	Cercocarpus
Ilex	Leguminosae	Pyrus (in part)
Bignoniaceae	Cercis	Rosa
Catalpa	Gleditsia	Sorbus
Chilopsis	Gymnocladus	Scrophulariaceae
Boraginaceae	Robinia	Paulownia (Nat.)
Ehretia	Leitneriaceae	Simarubaceae
Celastraceae	Leitneria	Ailanthus (Nat.)
Euonymus	Magnoliaceae	Sterculiaceae
Corylaceae	Magnolia	Fremontodendron
Carpinus	Meliaceae	Tiliaceae
Ostrya	Melia (Nat.)	Tilia
Ericaceae	Moraceae	Ulmaceae
Arbutus	Broussonetia (Nat.)	Celtis
Arctostaphylos	Morus	Ulmus
Andromeda	Toxylon (Maclura)	Planera
Kalmia		Vacciniaceae
		Vaccinium

TABLE IX

Type of Vessel Pits to Ray Cells

Family	Bordered	Simple	Family	Bordered	Simple
Aceraceae	X		Meliaceae	X	
Anacardiaceae		← X	Moraceae	X →	
Anonaceae	X		Myricaceae	X	
Aquifoliaceae	X		Myrsinaceae	X	
Araliaceae		← X	Myrtaceae	X →	
Betulaceae*	X	X	Nyctaginaceae	X	
Bignoniaceae	X →		Oleaceae	X	
Boraginaceae	X		Platanaceae	X	
Burseraceae		← X	Polygonaceae	X	
Canellaceae	X		Rhamnaceae	X	
Capparidaceae	X		Rhizophoraceae	X →	
Caprifoliaceae	X	X	Rosaceae	X	
Celastraceae	X		Rubiaceae	X	
Cornaceae	X		Rutaceae	X →	
Cyrillaceae	X		Salicaceae		X
Ebenaceae	X		Sapindaceae	X	
Ericaceae	X	X	Sapotaceae	X	X
Euphorbiaceae	X →		Simarubaceae	X →	
Fagaceae		← X	Sterculiaceae	X	
Hamamelidaceae		← X	Styracaceae	X	
Hippocastanaceae	X	X	Symplocaceae	X	
Juglandaceae		X	Theaceae	X	X
Koeberliniaceae	X		Tiliaceae	X	
Lauraceae		← X	Ulmaceae	X	X
Leguminosae†	X		Verbenaceae	X	
Leitneriaceae		X	Zygophyllaceae	X	
Magnoliaceae		← X			

* In *Betula* and *Alnus* the pits are bordered; in *Carpinus, Corylus,* and *Ostrya* simple pits predominate.

† In *Robinia* the pits are predominately simple.

TABLE X

Families with Representatives in Temperate North America
Exclusively Diffuse-porous

Aceraceae	Ericaceae	Rhizophoraceae
Amygdalaceae	Euphorbiaceae	Rosaceae
Apocynaceae	Grossulariaceae	Rubiaceae
Aquifoliaceae	Hamamelidaceae	Salicaceae
Berberidaceae	Hippocastanaceae	Sapotaceae
Betulaceae	Koeberliniaceac	Solanaceae
Boraginaceae	Magnoliaceae	Staphyleaceae
Burseraceae	Malvaceae	Styracaceae
Canellaceae	Melastomaceae	Surianaceae
Capparidaceae	Myricaceae	Symplocaceae
Caprifoliaceae	Myrsinaceae	Theaceae
Celastraceae	Myrtaceae	Theophrastaceae
Clethraceae	Nyctaginaceae	Thymelaeaceae
Combretaceae	Nyssaceae	Tiliaceae
Cornaceae	Olacaceae	Vacciniaceae
Corylaceae	Platanaceae	Verbenaceae
Cyrillaceae	Polygonaceae	Zygophyllaceae

TABLE XI

Ring-porous Woods of Temperate North America

Acacia	Dalea	Paulownia (Nat.)
Ailanthus (Nat.)	Diospyros	Pinckneya
Asimina	Ehretia	Prosopis
Broussonetia (Nat.)	Eysenhardtia	Ptelea
Bumelia	Fraxinus	Quercus
Castanea	Fremontodendron	Rhamnus
Castanopsis	Gleditsia	Rhus
Catalpa	Gymnocladus	Robinia
Celtis	Hicoria (Carya)	Sapindus
Cercis	Leitneria	Sassafras
Chilopsis	Melia (Nat.)	Sophora
Chionanthus	Morus	Toxylon
Cotinus	Parkinsonia	Ulmus

Wood Parenchyma

Parenchyma is a tissue concerned primarily with the storage and distribution of carbohydrates; the cells composing it are usually prismatic or isodiametric, have numerous simple pits, and retain their protoplasm as long as they are functional. Parenchyma of primary xylem is all vertical, whereas that of secondary wood is usually in two systems, namely, (*a*) vertical, or axial, called **wood** or **xylem parenchyma,** and (*b*) horizontal, or radial,

Fig. 22. — Crystalliferous wood parenchyma strands. Tangential section of *Hicoria cordiformis* (Bitternut Hickory), showing parts of four parenchyma strands, in two of which are large rhombohedral crystals of calcium oxalate. The other cells shown are fiber-tracheids. ×890.

termed **ray parenchyma** (see *Rays*). The elements of wood parenchyma are of two types, namely, (*a*) single, elongated cells, termed *fusiform wood parenchyma cells,* and (*b*) cell-series, called *wood parenchyma strands.*

A **fusiform wood parenchyma cell*** is derived from a fusiform

* The older terms, *substitute fiber* and *intermediate wood fiber,* are inappropriate since they obscure the fact that the cells are parenchyma.

cambial initial without subdivision or appreciable increase in length. Such cells are much less common than the strand type, but they characterize a few dicotyledonous woods and occur more or less sporadically in others.

A **wood parenchyma strand** (Fig. 24) is derived from a single fusiform cambial initial by segmentation of a mother cell into a vertical series of two to several individual cells. It has approximately the same length and shape as the initial. The terminal cells of a strand are square at one end and taper gradually or abruptly to a point at the other; when, as is usually the case, there are several cells in a strand, the middle ones are upright or more or less cubical. Since the strands themselves are vertical series and overlap or dovetail at the ends, their form is seen to best advantage in tangential section.

In some woods the number of cells to a strand varies considerably, whereas in others, especially those with storied structure, it is fairly constant. Strands in contact with large vessels are no longer than the metatracheal and diffuse strands of the same specimen, but usually the cells are broader and more numerous. Septate cells are common; those containing series of solitary crystals are frequently referred to as *chambered parenchyma*, although not all crystalliferous parenchyma cells are septate (Fig. 22). Large, thin-walled, distended *oil cells* (Fig. 23) are characteristic of certain woods (*e.g.*, Lauraceae), and globose crystalliferous cells are common in *Gingko*.

Wood parenchyma cells exhibit considerable variation in the thickness of the walls in different kinds of woods and sometimes also in different parts of the same specimen. The wall of a given cell may be uniform or very irregularly thickened. In the parenchyma terminating a season's growth of *Liriodendron*, the tangential walls are thin, whereas the radial and end walls are exceedingly thick and irregular. Disjunctive cells are common in dense woods, and are readily recognized, even when the processes are very short, by the sieve-pitting.

The pitting in wood parenchyma is greatly affected by the type of adjoining tissue. Where two parenchyma cells are in contact the pits are usually numerous, small, round or irregularly shaped, and sometimes clustered (sieve-pitting). In disjunctive terminal parenchyma cells the pit clusters are seen to best advantage in the radial section. In the wall of contact of any parenchyma cell

with a vessel, the pits often are of the same size and shape as their vascular complements; sometimes they are elongated and scalariformly arranged. Pits may or may not be present in the facets of the wall adjoining wood fibers.

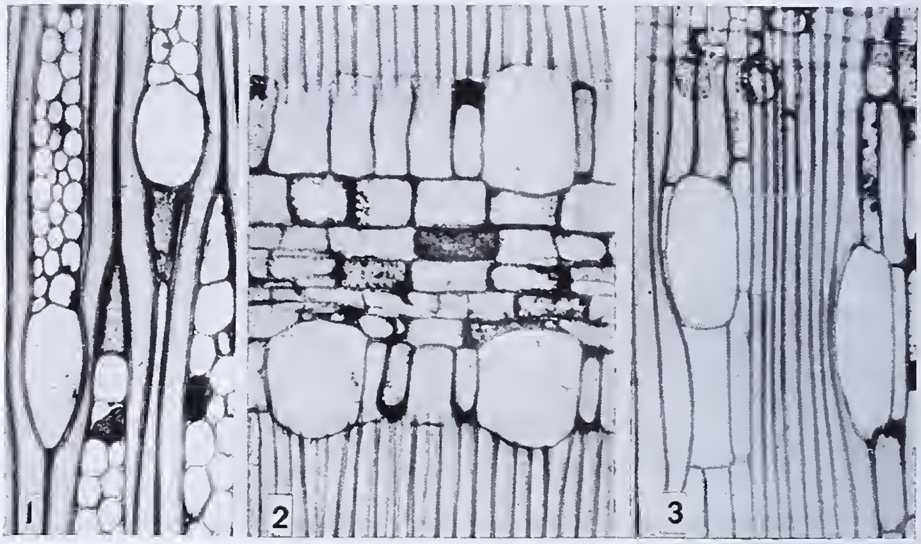


Fig. 23. — Oil cells in rays and wood parenchyma strands. ×115. (1) Tangential section of *Virola merendonis*, showing two oil cells in the margins of the rays. (2) Radial section of *Knema Alvarezii*, showing a heterogeneous ray with three marginal oil cells. (3) The same, showing two oil cells in wood-parenchyma strands.

In the Gymnosperms, wood parenchyma cells are normally in strands, but owing to the great length of the initials, the series are so long that the strand character is often rather obscure.* Wood parenchyma is absent from a few of the Gymnosperms (*e.g.*, *Taxus*, *Torreya*, *Araucaria*) and is rare or very sparingly developed in others (*e.g.*, *Abies* and *Tsuga*). In *Pinus* vertical parenchyma occurs only as the epithelium of resin ducts. In *Picea*, *Larix*, and *Pseudotsuga* there are also scattered strands on the outer face of the late wood, though often it is difficult to find them. The woods of the Cupressaceae and Taxodiaceae, on the other hand, are characterized by fairly abundant parenchyma; the strands are disposed either irregularly or zonately among the tracheids, from

* For this reason the cells are commonly known as *resin cells*. Further use of this term is to be discouraged, however, since the cell contents for the most part are not truly resinous.

which they are readily distinguished by their thinner walls, simple pits, and dark-colored contents (Fig. 24). Parenchyma in Gymnosperms is typically diffuse (*e.g.*, Cupressaceae, Taxodiaceae) or in isolated terminal strands (*e.g.*, *Picea*, *Larix*, *Pseudotsuga*); although zonately disposed and occasionally giving rise to fairly

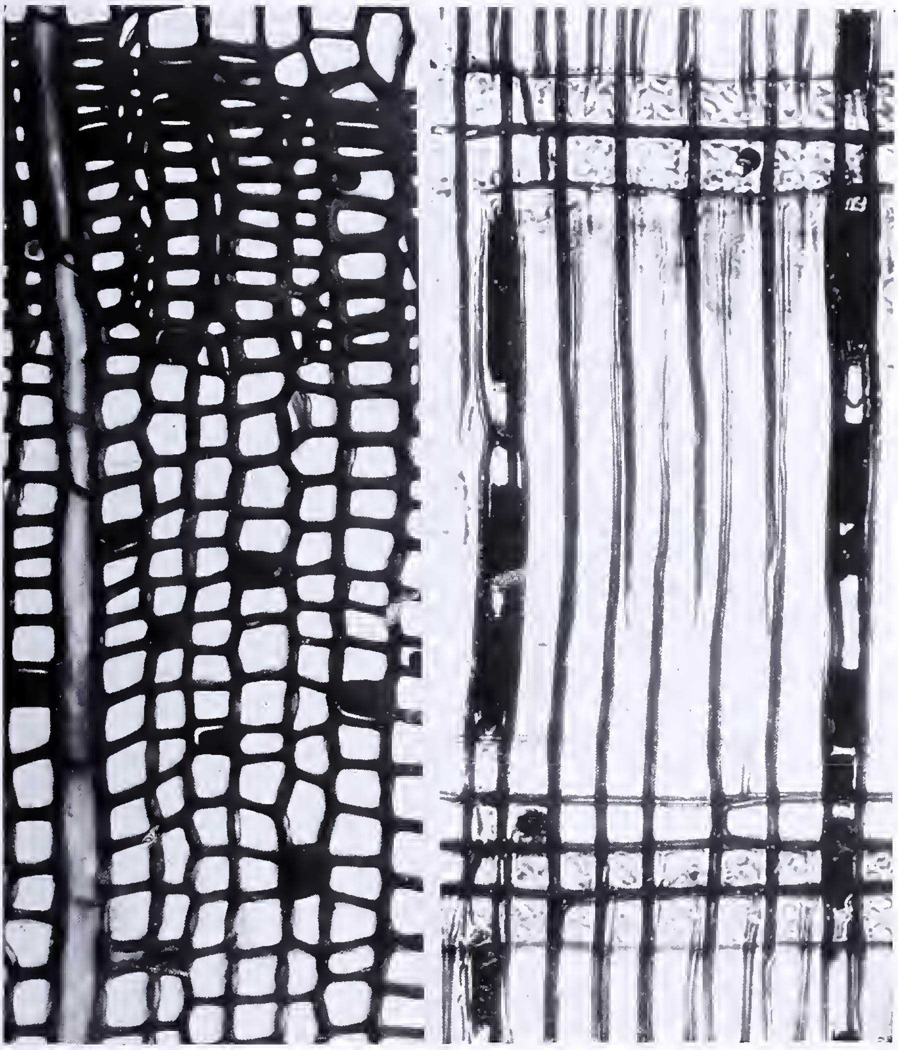


Fig. 24. — Diffuse parenchyma in *Sequoia sempervirens*. Cross and radial sections showing parenchyma cells with dark, gummy contents. ×250. (Photomicrographs by U. S. Forest Service.)

distinct concentric lines (*e.g.*, *Chamaecyparis thyoides*, *Juniperus virginiana*, *Taxodium*), it does not form solid laminae and is not

densely aggregated except in traumatic tissue and around resin ducts.

In the Dicotyledons, wood parenchyma varies in amount from little or none to great abundance, and in arrangement from scattered strands to aggregations in definite patterns, thus providing features of much importance in identifying woods. The general types of arrangement for which names are in common use are as follows: *Diffuse, i.e.,* single strands scattered irregularly among the wood fibers as seen on cross section (Fig. 24); *paratracheal, i.e.,* aggregated about the vessels (Fig. 25); *metatracheal, i.e.,* in concentric laminae (Fig. 26); *terminal, i.e.,* in a uniseriate, or multiseriate, or broken layer formed at the close of a season's growth (Fig. 26, No. 1). All these types or various combinations of them may be present in a single specimen, though if there is only one it is generally the paratracheal, occasionally the terminal. Wood parenchyma cells do not occur in independent radial rows.*

When parenchyma is well developed it gives rise to more or less distinctive patterns on cross sections of the wood. These usually appear lighter than the ground mass of fibers, but sometimes they are of the same color or darker. The distinctness of the patterns depends more on color contrast than relative proportion of the different tissues, and the contrast is generally increased by moistening the end of a specimen before examining with a hand lens. Sometimes parenchyma is more distinct in sapwood than in heartwood, particularly if the heartwood is oily, gummy, or resinous, but generally the opposite is true.

Some of the most common variations in the patterns of **paratracheal parenchyma** are conveniently designated as follows: *Vasicentric* when the parenchyma is in narrow to wide circles or ovals (Fig. 25, No. 1); *aliform* when it has wing-like lateral extensions (Fig. 25, No. 2); *confluent* when the extensions coalesce into tangential or diagonal lines or bands (Fig. 25, No. 3). In the typical forms the pores are completely imbedded. Detached poreless islands are not uncommon. All these variations are well illustrated in different woods of the Leguminosae.

Typical **metatracheal parenchyma** differs from confluent paratracheal types in that its development is largely independent of

* The upright cells of heterogeneous rays often appear in cross sections as radial rows of wood parenchyma cells.

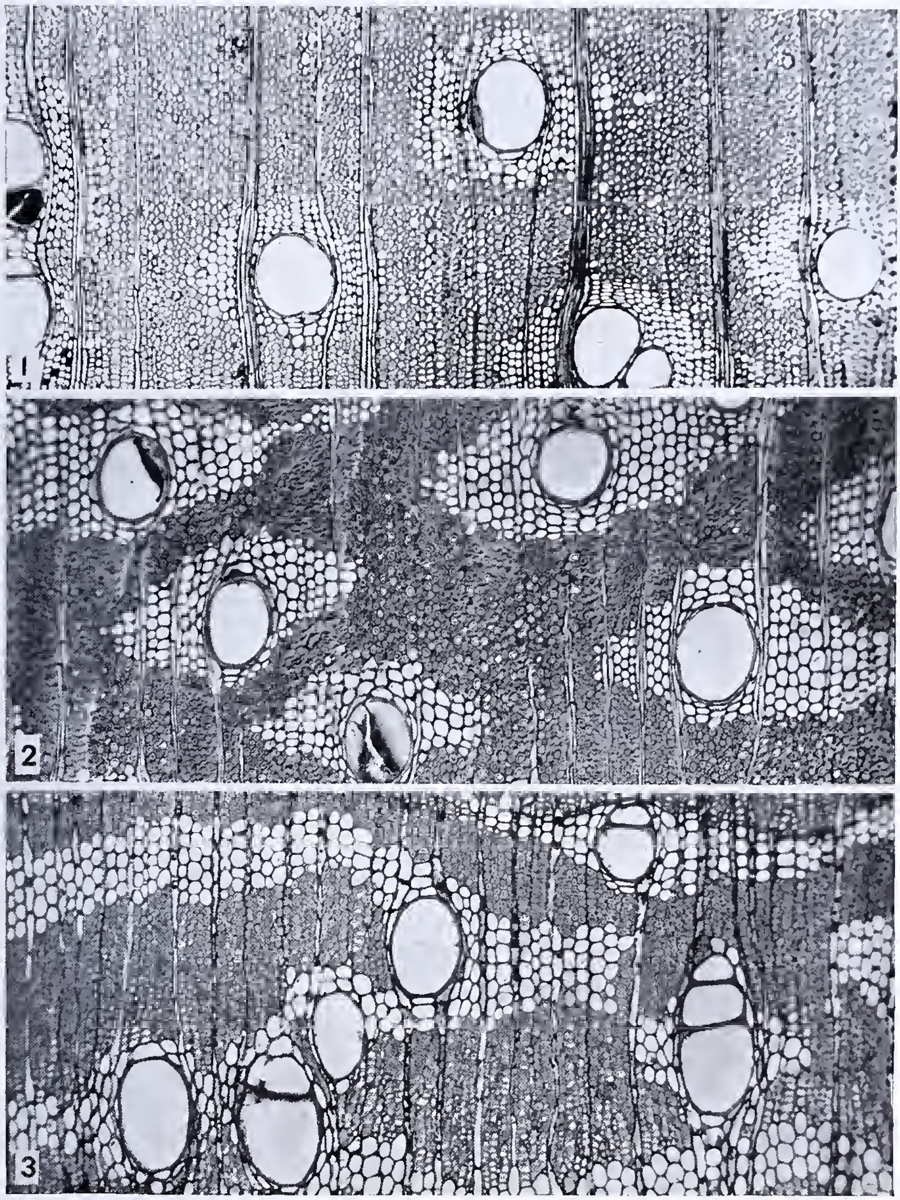


Fig. 25. — Types of paratracheal parenchyma. ×50. (1) Cross section of *Albizzia odoratissima*, showing vasicentric parenchyma. (2) Cross section of *Calophyllum Inophyllum*, showing aliform parenchyma. (3) Cross section of *Terminalia belerica*, showing confluent parenchyma. (Photomicrographs by Canadian Forest Products Laboratories.)

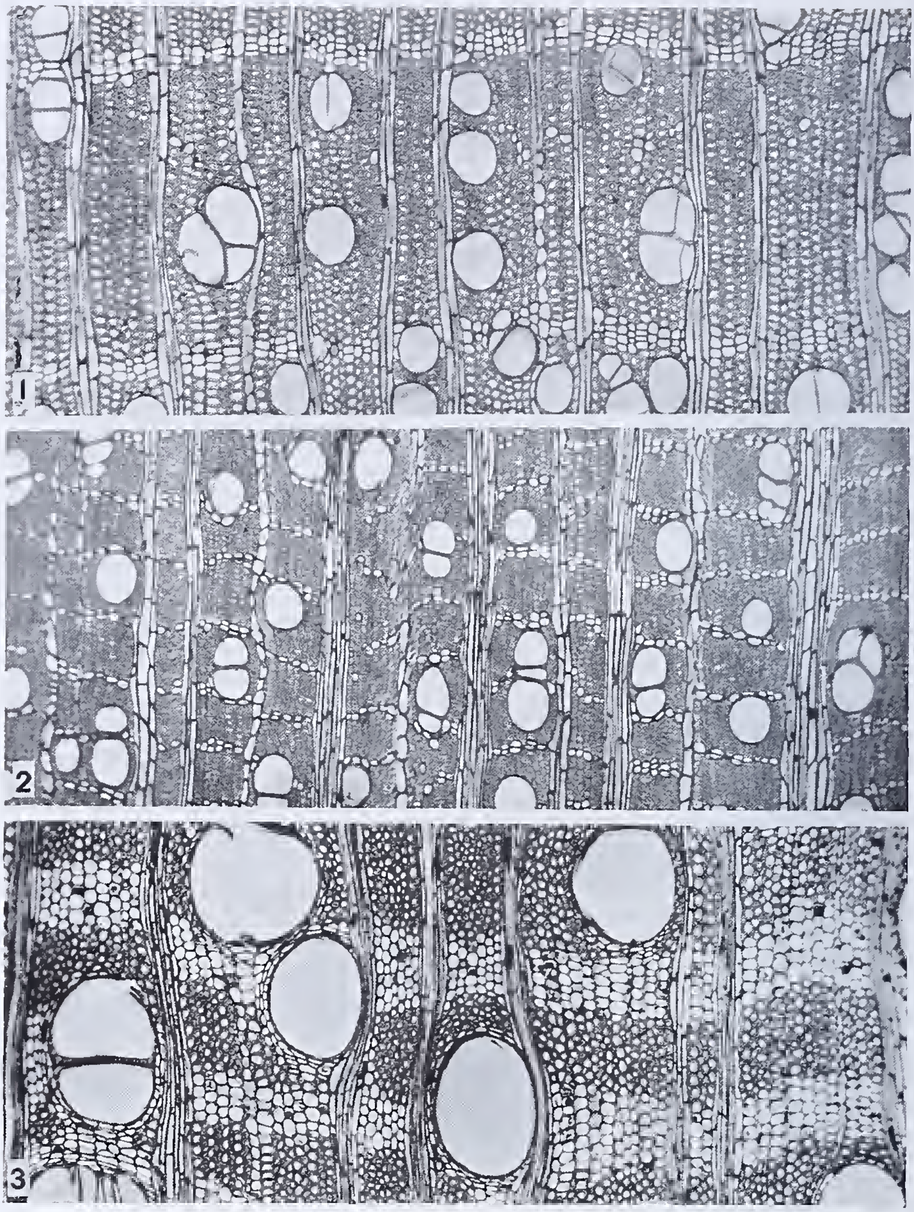


FIG. 26. — Terminal and metatracheal parenchyma. ×50. (1) Cross section of *Michelia champaca*, showing two bands of terminal parenchyma. (2) Cross section of *Saccopetalum tomentosum*, showing uniseriate or biseriate metatracheal parenchyma. (3) Cross section of *Stereospermum xylocarpum*, showing broad bands of metatracheal parenchyma. (Photomicrographs by Canadian Forest Products Laboratories.)

the pores. Even where the parenchyma bands are as wide as the intervening fiber layers, as in certain tropical woods, there is no appreciable widening to include the pores; in fact, the pores occur in both the parenchyma and the fiber layers, and a single pore may be situated across the line of intersection (Fig. 26, No. 3). Pores wholly within the fiber layers, however, always have at least a few cells of paratracheal parenchyma. Variations in metatracheal patterns are mostly in the width and spacing of the bands. Narrow rows of cells are characteristic of many genera. If the woods are diffuse-porous (*e.g.*, *Tilia*, *Diospyros* spp., various Anonaceae) the lines occur throughout the growth ring, though tending to become more numerous as the season advances. In ring-porous woods (*e.g.*, *Hicoria*, *Quercus*, *Castanea*) the concentric lines appear after the formation of the large pores and are best developed in wide growth rings, becoming progressively closer spaced and of more regular contour. Concentric parenchyma is highly characteristic of many tropical woods. Sometimes it is in lines which, in combination with the rays, form a pattern resembling a spider web (*e.g.*, Anonaceae), and sometimes it is in rather wide bands in distinct contrast to the alternate layers of wood fibers (*e.g.*, *Ficus*).

Terminal parenchyma differs from the metatracheal type chiefly in the matter of location (Fig. 26). In some woods (*e.g.*, *Salix*, *Populus*, *Liriodendron*) parenchyma is limited to a layer only one or two cells wide on the outer face of the late wood. In others terminal parenchyma occurs along with paratracheal (*e.g.*, *Fraxinus*) or metatracheal (*e.g.*, *Betula*) or in various combinations (*e.g.*, certain Leguminosae). In *Liriodendron*, *Magnolia*, and *Fraxinus* the radial and end walls of the terminal parenchyma cells are heavily sculptured. Some tropical woods (*e.g.*, *Swietenia*) have concentric parenchyma bands which appear to terminate definite seasonal growths, but may be only widely spaced metatracheal layers.

Wound parenchyma is of common occurrence in woods as a result of injury to the cambium. The cells are irregular in size, shape, and arrangement (Fig. 35), and ordinarily not in definite strands. Generally the walls are thick and abundantly pitted, and the cell contents are dark colored. Cross sections of wound parenchyma occluding tunnels made in the cambium by the larvae of certain insects are called **pith-flecks** (also *medullary spots*) (Fig. 27).

Fig. 27. — Pith fleck in *Acer rubrum* (Red Maple). Cross section showing also the structure of a diffuse-porous wood with solitary and multiple pores. ×40. (Photomicrograph by U. S. Forest Service.)

They are of common, but variable, occurrence in many fine-textured and diffuse-porous woods (*e.g.*, Aceraceae, Betulaceae, Rosaceae, Salicaceae). They may be abundant in certain stems or different parts of the same stem and absent from other individuals of the same species or other regions of the same stem. They are therefore not dependable features for diagnostic purposes, though their presence in abundance may assist in determining a species. For example, they are usually very numerous in *Betula populifolia*, *B. papyrifera*, and *B. nigra*, and infrequent in *B. lenta* and *B. lutea;* numerous in *Acer rubrum* and *A. saccharinum*, but usually wanting in *A. saccharum.*

Rays

Rays* are sheets or ribbons of tissue, mostly parenchyma, extending radially in the stems of Gymnosperms and Dicotyledons. As the first rays diverge with increase in diameter of the stem, additional ones arise between them from new sets of ray initials formed by division of fusiform cambial initials.† If the divisions of the initial are all transverse, the resulting ray is uniseriate; if both vertical and transverse, biseriate to polyseriate, at least in part. Two or more fusiform cells may unite to form the initial groups for very high or very wide rays. Once a ray has been initiated it normally is continued indefinitely‡ on both sides of the

* There are two fundamentally different types of rays, namely, (*a*) *medullary rays* proper and (*b*) *vascular rays*. The term medullary is commonly applied to all rays because their earlier stages appear as radiating portions of the pith (medulla). It is a misnomer for the usual type of rays in secondary xylem and phloem, and its usage should be confined to the sheets of parenchyma extending laterally from pith to cortex and axially from node to node in vines and herbs with dissected vascular cylinders, or at most to the wide rays of fundamental tissue separating well-defined *primary* vascular bundles. The apparent extensions of these rays by the interfascicular cambium are sometimes referred to as *primary medullary rays* to distinguish them from the so-called *secondary* rays that are formed by the fascicular cambium, but the terms are unnecessary and likely to be confusing, since all of the vascular rays are of secondary origin.

† Small rays may also develop from large ones through the reversion of some of the ray initials to fusiform.

‡ When on cross or radial sections a ray appears to be discontinuous, it is probable that it has merely been missed by the plane of section. This emphasizes the importance of making cross sections exactly at right angles to the axis of growth, and radial sections as nearly as possible parallel with the rays. Since length of a ray is indeterminate, the only useful dimensions are height and breadth.

cambium (Fig. 5, p. 13), although it may undergo various changes in form. In describing whole stems it often is convenient to distinguish the part of the ray internal to the cambium as a **wood ray** or **xylem ray**, and the external part as a **phloem ray.**

In the typical Gymnosperms the rays are for the most part one cell wide (uniseriate) and from 1 to 20, sometimes up to 50, cells high. Occasionally they are biseriate in part; those that contain resin ducts (viz., *Pinus, Picea, Larix, Pseudotsuga*) are considerably enlarged in the middle, or *fusiform* as seen in the tangential section (Fig. 37). Rays much higher and wider than normal, and with or without resin ducts, may develop traumatically. *Gnetum* and *Ephedra* have rays of the dicotyledonous type.

Xylem rays of Gymnosperms are composed of radially elongated cells, in most cases wholly parenchyma. In some genera, however, ray tracheids are present either as a constant feature (*e.g., Pinus, Picea, Larix, Pseudotsuga, Tsuga, Cedrus*) or of more or less sporadic occurrence (*e.g., Abies, Sequoia, Chamaecyparis, Thuja, Juniperus, Libocedrus*). They are most abundantly developed in *Pinus,* especially in the species of the Pitch Pine group, and series of them, sometimes several cells high, are marginal and not infrequently *interspersed, i.e.,* separating the rows of parenchyma cells, and sometimes constitute entire low rays. In the other woods they occur singly or in interrupted or continuous rows along either or both margins of the ray and also as very irregularly formed cells in independent uniseriate or biseriate rows. Ray tracheids and ray parenchyma cells appear to be interchangeable, *i.e.,* the same cambial initial may give rise to first one type and then the other.

Ray tracheids are distinguished from the ray parenchyma cells by their bordered pits, which often are most distinctive in their end walls. They are also devoid of visible contents, whereas the parenchyma cells in the sapwood contain protoplasm and those in heartwood usually have dark-colored resinous deposits in greater or less abundance. In the young root, and sometimes in the young stem also, special upright or oblique forms occur, which apparently are transitional from vertical tracheids to ray tracheids. Spiral thickenings of the secondary wall are characteristic of the ray tracheids of *Pseudotsuga* and certain Asiatic species of *Picea,* and are of sporadic occurrence elsewhere. The upper, lower, and end walls of the ray tracheids of the many species of *Pinus* constituting

the Pitch Pine group are usually distinctly sculptured (Fig. 28, No. 2), being sometimes merely *dentate* but in other cases *reticulate*, *i.e.*, with the projections of the wall more or less connected across the cell lumen.

Ray parenchyma cells vary in outline, thickness of wall, nature of pitting, and in contents. The cells in contact with a large vessel may be compressed laterally, while those in a layer of wood parenchyma are dilated. The end walls may be vertical, oblique, or curved, and thin and unpitted or thicker and conspicuously pitted. As seen in radial sections, the cells are usually prismatic, but may be enlarged in the middle, or some or all of the marginal cells may be very irregular in form. The upper and lower walls may be thin and sparsely pitted or thick and abundantly pitted; in the Pinaceae (and many Dicotyledons) there are numerous *blind pits* which permit communication with interstitial spaces. The pits in the lateral walls, where in contact with the vertical tracheids, are highly distinctive; they are always simple, but their complements in the tracheary cells are, with few exceptions (*e.g.*, early wood of *Pinus*), provided with borders. The size and form of these lateral pits and the number in a cross-field* of the early wood provide important diagnostic features. Thus in the species of *Pinus* constituting the White and the Red Pine groups, the pits are large and only one or two to a cross-field† (Fig. 28, No. 1), whereas in the other species of *Pinus* and nearly all of the other Gymnosperms the pits are smaller and more numerous.

The rays of dicotyledonous woods are of all sizes from low and uniseriate and scarcely distinct even under a hand lens (*e.g.*, *Salix* and *Populus*) to very high, broad, and conspicuous (*e.g.*, *Quercus*, Proteaceae, Dilleniaceae). In a given wood the range in height is always greater than in width. In some cases the rays are of two distinct size classes, for example in *Quercus*, which has many low, uniseriate rays and relatively few large rays that sometimes are over 50 cells broad and several hundred cells high. Rays often widen appreciably at the termination of a growth ring, and there

---

* A *cross-field* is the rectangular facet of wall where a ray cell and a vertical tracheid are in contact or their lateral walls appear to intersect. The reduced area of the cross-fields in the late wood affects the number, form, and sometimes the arrangement of the pits.

† Similar large pits also characterize *Dacrydium*, *Microcachrys*, *Phyllocladus*, and *Sciadopitys*.

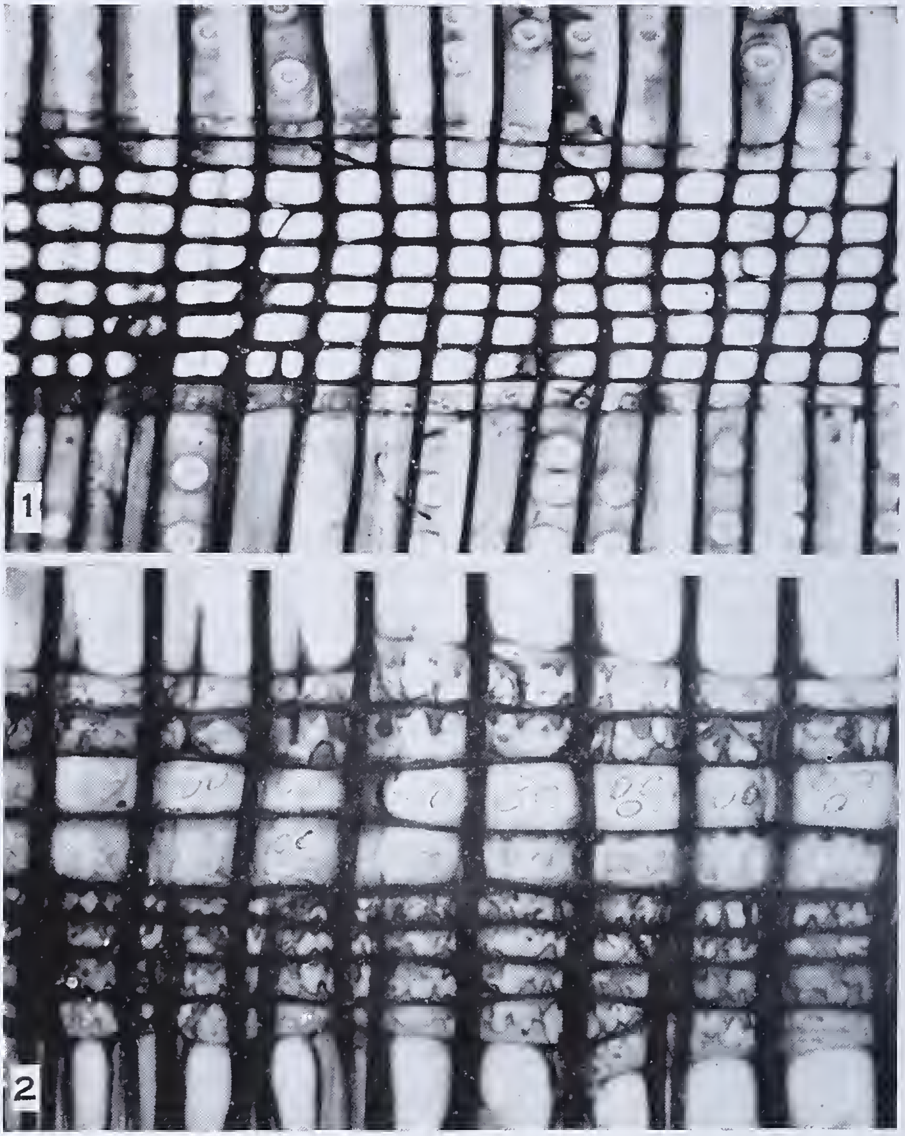


FIG. 28. — Rays in White and Shortleaf Pines. (1) Radial section of *Pinus strobus* (White Pine), showing three marginal rows of smooth-walled ray tracheids and six rows of parenchyma cells mostly with one large simple pit in each cross-field. ×175. (2) Radial section of *Pinus echinata* (Shortleaf Pine), showing six rows of ray tracheids with dentate upper and lower walls and two rows of parenchyma cells with two to several small pits in each cross-field. ×250. (Photomicrograph by U. S. Forest Service.)

is usually a depression in the boundary crossing a wide ray. Narrow rays are sometimes arranged in groups (Plate V, Figs. 3, 4), each of which appears to the unaided eye or at low magnification as a single large or **aggregate ray** (*e.g.*, *Carpinus*, *Corylus*, *Alnus*). In woods with storied structure the rays, if of fairly uniform height,

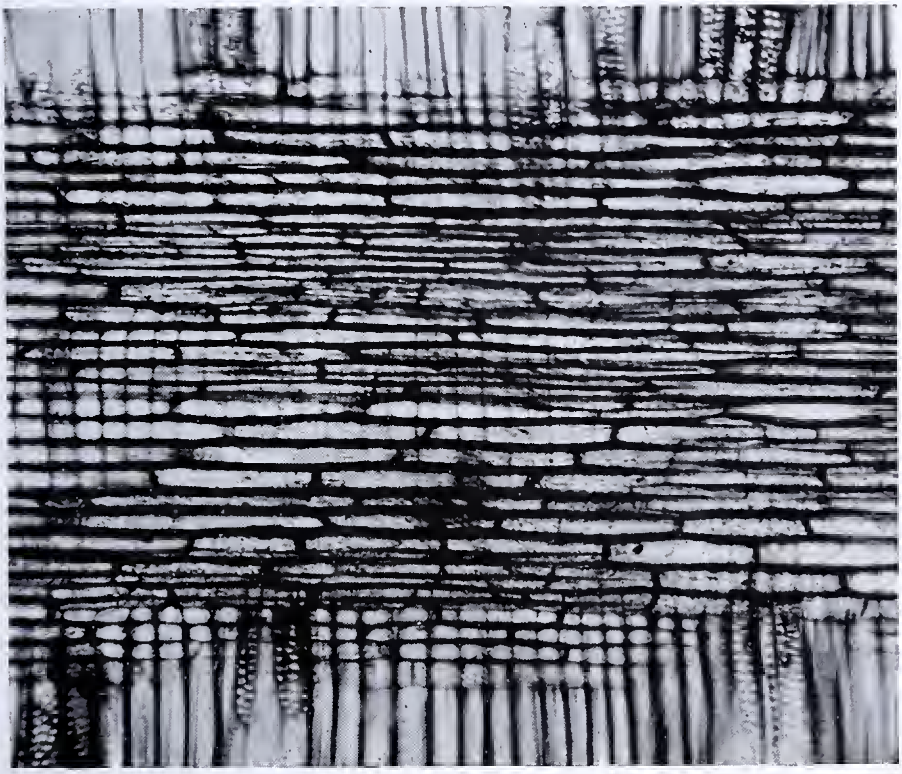


FIG. 29. — Homogeneous ray in *Acer saccharum* (Sugar Maple). Radial section showing all of the ray cells procumbent, or radially elongated. ×50.

are all in horizontal seriation (Fig. 40, p. 82); if of different heights, the taller rays may occupy more than one tier (Fig. 41, p. 84), but usually are more or less constricted between successive tiers and may appear, in tangential view, to be *vertically fused.*

The ray tissue of dicotyledonous woods, with rare and unimportant exceptions, is entirely parenchyma, but the cells exhibit a variety of forms and arrangements, especially as seen in radial sections. A ray composed wholly of *procumbent*, or radially elongated, cells is referred to as **homogeneous** (Fig. 29), and one composed of cells of different morphological types, as **heterogeneous**;

the two types tend to intergrade. In a typical heterogeneous ray there is a multiseriate middle layer of procumbent cells and uniseriate margins composed of cells that are *upright* or *square** (Figs. 23, 30, 31). The relative proportions of the two parts are subject to great variation. Not infrequently there are two or more multiseriate layers of procumbent cells separated by few to several radial series of upright or square cells; such a ray appears in tangential view to be composed of two or more vertically fused

Fig. 30. — Palisade type of upright ray cells. Radial section of *Tovomitopsis multiflora*, showing series of very tall and narrow cells along the margin of a heterogeneous ray. ×135.

heterogeneous rays. The upright cells are not always readily distinguished from the cells of parenchyma strands; sometimes they are much elongated, pointed at the distal end, and set in compact marginal rows suggesting a *palisade* (Fig. 30).

* There are numerous deviations from the typical forms and various gradations in heterogeneity, but any ray with upright cells or a considerable proportion of square cells should be classified as heterogeneous even if procumbent cells are entirely absent. Uniseriate rays without procumbent cells are of common occurrence in association with typical heterogeneous rays.

Upright cells tending to form a sheath about the smaller cells of a multiseriate ray or the multiseriate part of a ray are called **sheath cells*** (Fig. 41, p. 82); they represent new peripheral additions to the ray. The rays of certain woods of the Bombacaceae, Sterculiaceae, and Tiliaceae are characterized by **tile cells**, which are a special type of small, radially flattened, upright cells

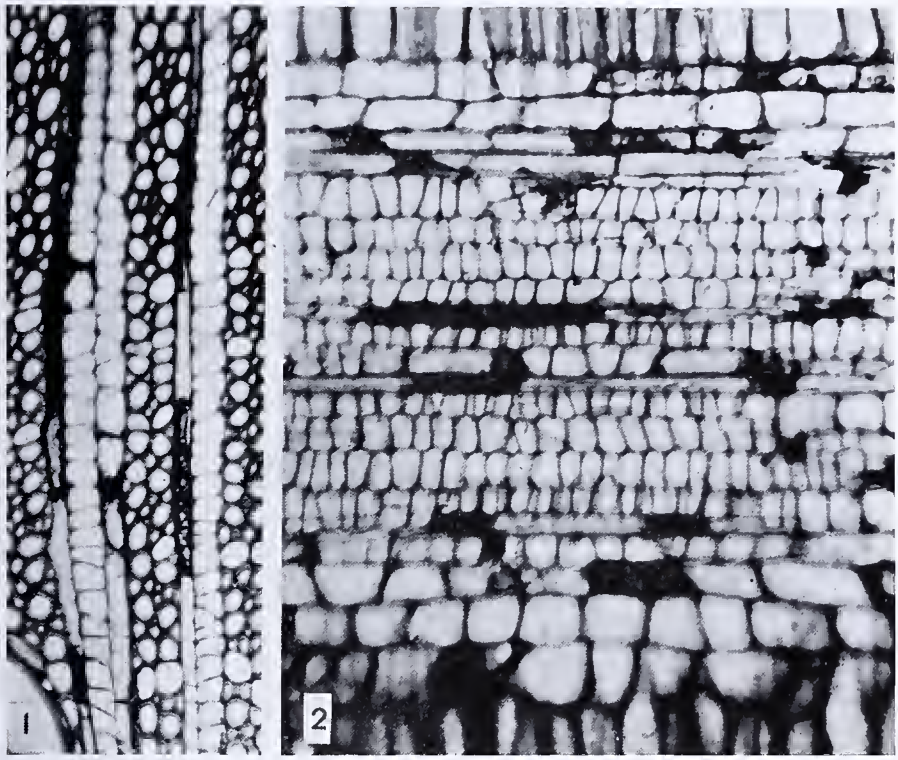


Fig. 31. — Tile cells in *Luehea Seemanii*. ×175. (1) Cross section showing two rays with radially flattened cells, called tile cells. (2) Radial section showing several rows of tile cells in the interior of a ray.

occurring in indeterminate horizontal rows interspersed among, and usually of about the same height as, the procumbent cells (Fig. 31). Another highly characteristic feature is that the cells are apparently empty (except for crystals, in some instances), whereas the cells in the other rows have conspicuous dark-colored

---

* See Chattaway, M. M.: Ray development in the Sterculiaceae. *Forestry* 7: 2: 92–108, Dec. 1933.

contents. According to Chattaway,* tile cells contain protoplasm and conspicuous nuclei only in the immediate neighborhood of the cambium, and they lose their contents at an early stage. The cambial initials of the tile cells and procumbent cells are of approximately the same size, and so are the mother cells at first. Subsequently, the one that is to become a procumbent cell elongates radially, while the other divides and keeps on dividing until the procumbent cell has attained its full length, by which time there may be from 5 to 10, or even 14, upright cells corresponding to one that is horizontally elongated.

Among the other special structures in the xylem rays of certain Dicotyledons are intercellular canals or gum ducts (see Table XIV) and intercellular cavities; laticiferous cells and tubes connecting with vertical tubes in the bark or pith, or both (*e.g.*, certain Moraceae, Anacardiaceae, and Apocynaceae); tanniniferous tubes (in all of the Myristicaceae, according to Garratt†), oil cells (*e.g.*, certain Anonaceae, Canellaceae, Lauraceae, Magnoliaceae, Myristicaceae); aggregates of resinous cells, in certain Myrsinaceae; large cells containing cystoliths of calcium oxalate, in Opiliaceae‡; cells containing bundles of raphides, as in *Curatella;* and sclerotic cells, as occasionally in *Piratinera* and *Gymnocranthera.* Rhombohedral crystals of calcium oxalate are of common occurrence, either singly, or two or more in a septate cell. The author has observed trabeculae in some of the ray cells of *Aegiceras* sp. (Yale No. 22,906).

---

* Chattaway, Margaret M.: Tile-cells in the rays of the Malvales. *The New Phytologist* 32: 4: 261–273, Nov. 6, 1933.

Webber, Irma E.: The bearing of upright ray cells in the wood of *Hibiscus mutabilis* L. on usage of the term tile cell. *Tropical Woods* 37: 9–13, March 1, 1934.

† Garratt, George A.: Systematic anatomy of the woods of the Myristicaceae. *Tropical Woods* 35: 6–48, Sept. 1, 1933.

‡ See *Tropical Woods* 3: 10–12, Sept. 1925.

TABLE XII

Type of Rays in Certain Dicotyledonous Woods

Genus	Homogeneous	Heterogeneous
Acacia	X	
Acer	X	
Aesculus		← X
Ailanthus (Nat.)		X
Alnus	X	
Amelanchier		X
Amyris	X	
Andromeda		X
Anona		← X
Arbutus		X
Arctostaphylos		X
Asimina		X
Avicennia		X
Betula	X	
Broussonetia (Nat.)		X
Bumelia		X
Bursera		X
Carpinus	X	
Castanea		← X
Castanopsis		← X
Catalpa	X →	
Ceanothus		X
Celtis		X
Cercis	X	
Cercocarpus	X	
Chilopsis		X
Chionanthus		← X
Chrysophyllum		X
Cladrastis	X →	
Cornus		X
Cotinus		X
Crataegus	X →	
Cyrilla		X
Diospyros		X
Eucalyptus (Int.)	X →	
Fagus		← X
Ficus	X	
Fraxinus	X	
Fremontodendron		X
Gleditsia	X	
Gordonia		X
Guaiacum	X	
Gymnocladus	X	
Hamamelis		X
Hicoria (Carya)	X →	
Ilex		X
Juglans	X →	
Kalmia		X
Leitneria		X
Liquidambar		X
Liriodendron		← X
Magnolia		X
Melia (Nat.)		X
Mohrodendron		X
Morus		X
Myrica		X
Nyssa		X
Ocotea		X
Olneya	X	
Ostrya		X
Oxydendrum		X
Parkinsonia	X	
Paulownia (Nat.)		X
Persea		X
Planera		X
Platanus	X	
Populus	X	
Prosopis	X	
Prunus		← X
Ptelea		
Pyrus	X	
Quercus	X →	
Rhamnus		← X
Rhizophora		X
Rhododendron		X
Rhus	X	
Robinia	X →	
Salix		X
Sambucus		X
Sapindus	X	
Sassafras		X
Sideroxylon		X
Swietenia		X
Symplocos		X
Tilia	X	
Toxylon	X →	
Ulmus	X	
Umbellularia	X →	
Vaccinium		X
Viburnum		X
Xanthoxylum		X

Arrows indicate transitions from the prevailing type.

Tyloses and Tylosoids

A **tylosis** is a proliferation of the protoplast of a ray or wood parenchyma cell through a pit-pair into the lumen of an adjacent inactive tracheary element, where it may or may not divide (Fig. 32). Tyloses occur occasionally in the vertical tracheids of Gymnosperms, particularly in the wood of roots. They are common in

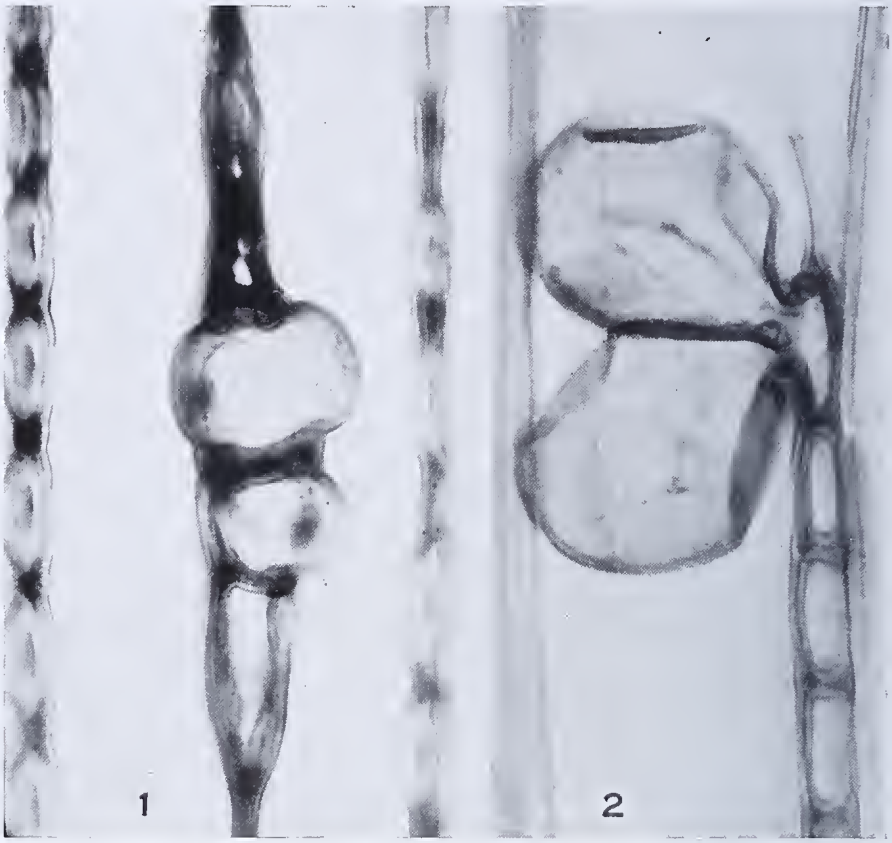


Fig. 32. — Formation of tyloses. ×680. (1) Tangential section of *Pinus resinosa*, showing proliferation of two ray parenchyma cells into the lumina of the adjacent vertical tracheids. (2) Tangential section of *Aesculus octandra*, showing two tyloses that have grown out of one ray parenchyma cell into a vessel. (Photomicrographs by U. S. Forest Service.)

vessels, and may be few (*e.g.*, *Aesculus*, *Platanus*) or many crowded together (*e.g.*, *Castanea*, *Hicoria*, *Morus*, *Robinia*), and either with or without visible contents, such as starch, resins, gums, and crystals. Usually the walls are thin and unpitted, but sometimes they are thicker and distinctly pitted, and occasionally resemble

stone cells (Fig. 33). These sclerotic tyloses are characterized by exceptionally thick, laminated walls and ramiform pits; they are of common occurrence in *Piratinera* and sporadic in other dense tropical woods (*e.g.*, *Mespilodaphne*, *Eusideroxylon*, *Pera*,

FIG. 33. — Sclerotic tyloses. Cross section of *Monotes macrantha*, showing part of a pore filled with tyloses. The simple pits have coalescent canal-like cavities (ramiform pits). In contact with the pore at the left is a uniseriate ray with dark-colored contents. The thick-walled cells at the top are fiber-tracheids. ×890.

Gymnocranthera). Tyloses in large vessels are plainly visible when abundant, their high luster giving them a froth-like appearance.

Although tyloses may occur in any part of the sapwood where water conduction is reduced, they are most abundantly developed, as a rule, in the region that is being transformed into heartwood. According to Kirsch* (p. 406), " The occurrence of the tyloses in this region is just what would be expected from the conditions that prevail in the vessels at this time. The conductive function is being taken over by the vessels of more recent formation and the sap is thus gradually withdrawn from the older ones. The pressure inside the latter is therefore greatly reduced, while the parenchyma cells that abut on them are in a high state of turgescence. The parenchyma cells, possessing a greater turgescence than the adjoining vessels, begin to extend, since they are in a state of active growth, and the pit being the weakest point in the wall of the vessel, they project into it and push in the closing membrane, finally rupturing it, thus gaining access to the lumen."

Tyloses, especially when abundant, are of considerable diagnostic value, but their absence from a small specimen is not necessarily significant. The closing of the vessels greatly reduces the permeability of wood, a matter of technical importance in the treatment of wood with preservatives or in the selection of material for tight cooperage.†

A **tylosoid** (Fig. 37) is a tylosis-like intrusion of a parenchyma cell into an intercellular space. It differs from a tylosis in that it does not pass through the cavity of a pit. Resin canals and the cavities left by the disintegration of protoxylem elements (as in ferns) may become partially or completely closed by tylosoids, that is, by the proliferation of the surrounding parenchyma cells. (See *Intercellular Canals.*) True tyloses may possibly occur in intercellular spaces through the proliferation of the protoplasts through blind pits, but if so they have not been observed.

---

* Kirsch, Simon: On the development and function of certain structures in the stipe and rhizome of *Pteris aquilina* and other Pteridophytes. *Trans. Royal Soc. Canada* (Ottawa) (3rd ser.) 1: 4: 353–412, 1908.

† See Gerry, Eloise: Tyloses; their occurrence and practical significance in some American woods. *Journ. Agr. Research* (Washington, D. C.) 1: 6: 445–469, March 25, 1914.

TABLE XIII

OCCURRENCE OF TYLOSES AND GUM DEPOSITS IN VESSELS OF CERTAIN DICOTYLEDONOUS WOODS

Genus	Tyloses	Gum	Genus	Tyloses	Gum
Acacia	few	common	Leitneria	absent	
Acer	absent	occasional	Liquidambar	common	
Aesculus	few	"	Liriodendron	"	
Ailanthus (Nat.)	absent	common	Magnolia	"	
Alnus	"		Melia (Nat.)	few	common
Amelanchier	"		Mohrodendron	absent	
Amyris	"	common	Morus	abundant	occasional
Anona	"		Nyssa	absent	common
Arbutus	"	common	Olneya	common	"
Arctostaphylos	"	"	Ostrya	absent	
Asimina	common		Oxydendrum	"	
Avicennia	absent		Parkinsonia	abundant	common
Betula	"	occasional	Paulownia (Nat.)	common	
Broussonetia (Nat.)	common	common	Persea	"	
Bumelia	"		Planera	absent	
Bursera	absent		Platanus	few	
Carpinus	"		Populus	common	
Castanea	abundant		Prosopis	absent	common
Castanopsis	common		Prunus	"	"
Catalpa	abundant		Ptelea	common	
Celtis	common		Pyrus	absent	
Cercidium	absent		Quercus (white)	abun-few	
Cercocarpus	"		" (red)	few-abun.	
Chilopsis	abundant		" (live)	"	
Cladrastis	absent	common	Rhamnus	absent	common
Cornus	"		Rhizophora	"	
Cotinus	abundant	common	Rhododendron	absent	
Cratægus	absent		Rhus	abundant	common
Diospyros	"		Robinia	abundant	
Eucalyptus (Int.)	common	common	Salix	common	
Fagus	"		Sambucus	"	
Ficus	abundant		Sapindus	absent	common
Fraxinus	abun-few	rare	Sassafras	common	
Fremontodendron	absent		Swietenia	absent	
Gleditsia	"	common	Symplocos	"	
Guaiacum	"	"	Tilia	"	
Gymnocladus	"	"	Toxylon	abundant	common
Hamamelis	"		Ulmus	few-abun.	
Hicoria (Carya)	abundant		Umbellularia	absent	
Ilex	absent		Vaccinium	"	
Juglans	abundant		Viburnum	"	common
Kalmia	absent		Xanthoxylum	absent	occasional

Intercellular Canals and Cavities

Intercellular canals in the woods of Gymnosperms are known as **resin ducts.** They are long, narrow channels surrounded by one or more layers of parenchyma cells which constitute the **epithelium.** In *Pinus* the epithelial cells are large, irregular, and so thin walled

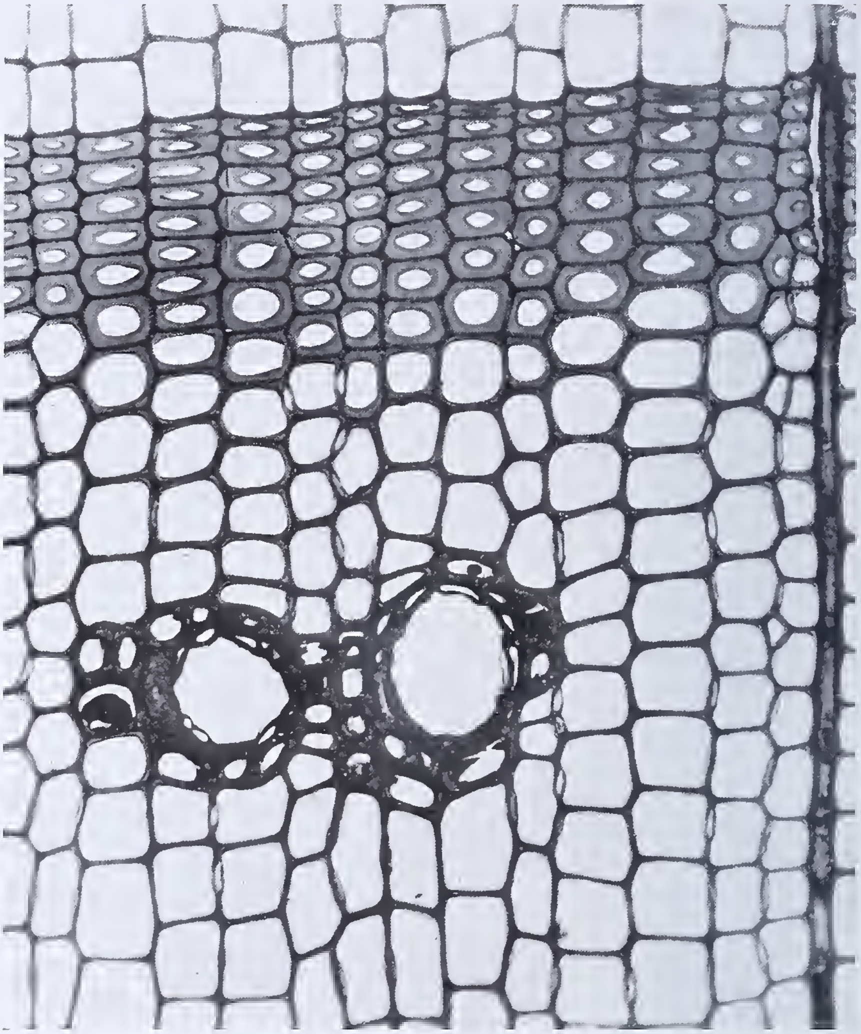


Fig. 34. — Cross section of *Pseudotsuga taxifolia* (Douglas Fir), showing thin-walled tracheids of the early wood and thick-walled fiber-tracheids of the late wood. At the right is a uniseriate ray and near the center are two vertical resin ducts with thick-walled epithelium. ×160.

that they are likely to be torn out in sectioning, whereas in other genera they are, for the most part, small, rounded on the

inner face, and as thick walled and resistant as the surrounding cells.

As to position, resin ducts are *vertical*, or *axial*, *i.e.*, among the tracheids, and *horizontal*, or *radial*, *i.e.*, in enlarged, or fusiform, rays; as to occurrence, they are said to be *normal* when of general distribution and *traumatic* when sporadic or obviously the result of wounds.* Anastomosing vertical and radial ducts are charac-

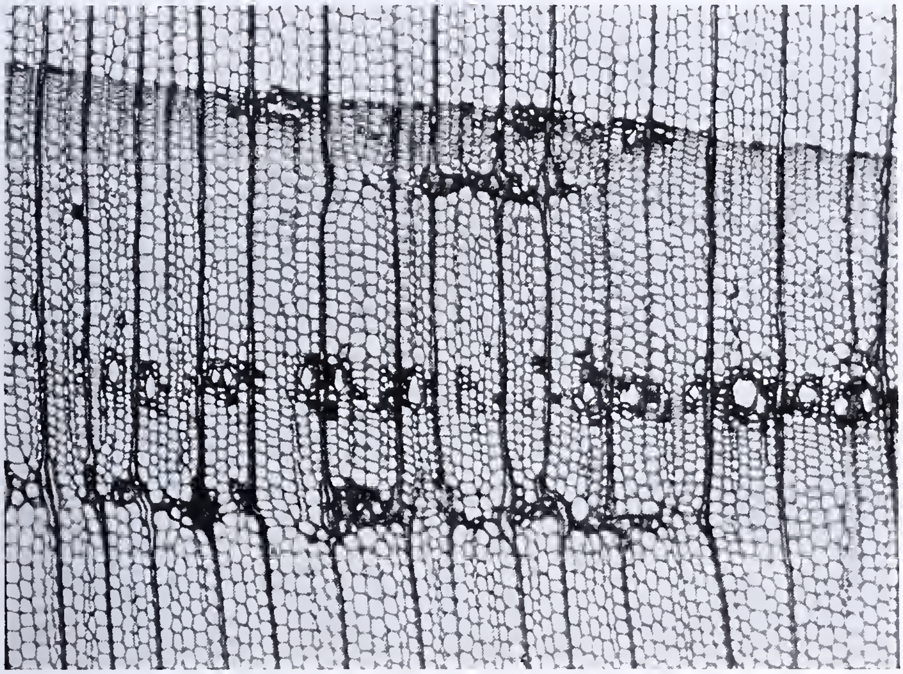


Fig. 35. — Wound parenchyma and traumatic resin ducts in *Tsuga heterophylla* (Western Hemlock). ×50. (Photomicrograph by U. S. Forest Service.)

teristic of *Pinus* (Fig. 5, p. 13), *Picea*, *Larix*, and *Pseudotsuga* (Fig. 34), but in *Keteleeria* only vertical ducts are normally present. Vertical resin ducts may develop as a result of injury to the cambium, both in woods with normal ducts and in some without,

* See Thomson, R. B., and H. B. Sifton: Resin canals in the Canadian spruce (*Picea canadensis* [Mill.] B.S.P.); an anatomical study, especially in relation to traumatic effects and their bearing on phylogeny. *Phil. Trans. Royal Soc. London* (ser. B) 214: 65–111, Nov. 5, 1925.

Bannan, M. W.: Factors influencing the distribution of vertical resin canals in the wood of the larch, *Larix laricina* (Du Roi) Koch. *Trans. Royal Soc. Canada*, 3rd ser., sec. V, vol. 27, pp. 203–217. Ottawa, 1933.

namely, *Cedrus, Sequoia, Abies,* and *Tsuga heterophylla* (Fig. 35). The ducts recognized as traumatic are disposed in short to long series parallel to the growth rings, whereas those considered as of normal occurrence are solitary or in scattered tangential groups of two or three ducts each. Short traumatic ducts are frequently called *resin cysts.* In woods other than *Pinus,* all of the axial resin ducts are constricted at intervals, and often what appears as a single vertical canal is in reality a series of resin cysts. Traumatic radial ducts of large size occur in *Cedrus,* but always in association with vertical ducts.

Resin ducts are largest and most numerous in *Pinus.* The vertical ones are mostly solitary and fairly well distributed throughout the growth ring and usually are readily visible to the unaided eye. On longitudinal surfaces they appear as long, delicate lines like pin scratches, with resinous contents. In the other genera the ducts are smaller, often indistinct and sometimes invisible without a lens, and are fewer and more irregularly distributed, often more or less grouped. Radial ducts are more uniformly distributed than the vertical. Occasionally in some genera (*e.g., Picea, Pseudotsuga*) rays are found with more than one duct each (Fig. 37, No. 1).

Resin ducts originate in the cambial zone in response to a special stimulus or irritation, and the intercellular spaces develop schizogenously, *i.e.,* by the separation of the walls of the inner epithelial cells. Except in *Pinus,* the space forms very early and is immediately followed by the secondary thickening of the walls of all or of most of the cells. In *Pinus,* however, the innermost epithelial layer is composed of globose cells (Fig. 5) that remain thin walled and frequently do not split apart the first year and sometimes never form a permanent canal. Usually, however, some or all of the cells eventually collapse, leaving a large opening in the middle (Fig. 36). This canal may become closed again by *tylosoids,* the tylosis-like proliferations of certain epithelial cells that have retained their cytoplasm longer than the others. Among the thick-walled epithelial cells of most of the other genera there are usually some thin-walled cells which may proliferate in the same manner; in some instances these tylosoids develop a thick secondary wall (Fig. 37).

The common forms of intercellular canals in dicotyledonous woods are usually known as **gum ducts**, although their contents

vary greatly in composition and may be resinous, oily, gummy, mucilaginous, etc. The canals may be either (apparently) normal or traumatic, and either axially or radially disposed, rarely in both planes. Normal vertical canals occur in tropical woods of several

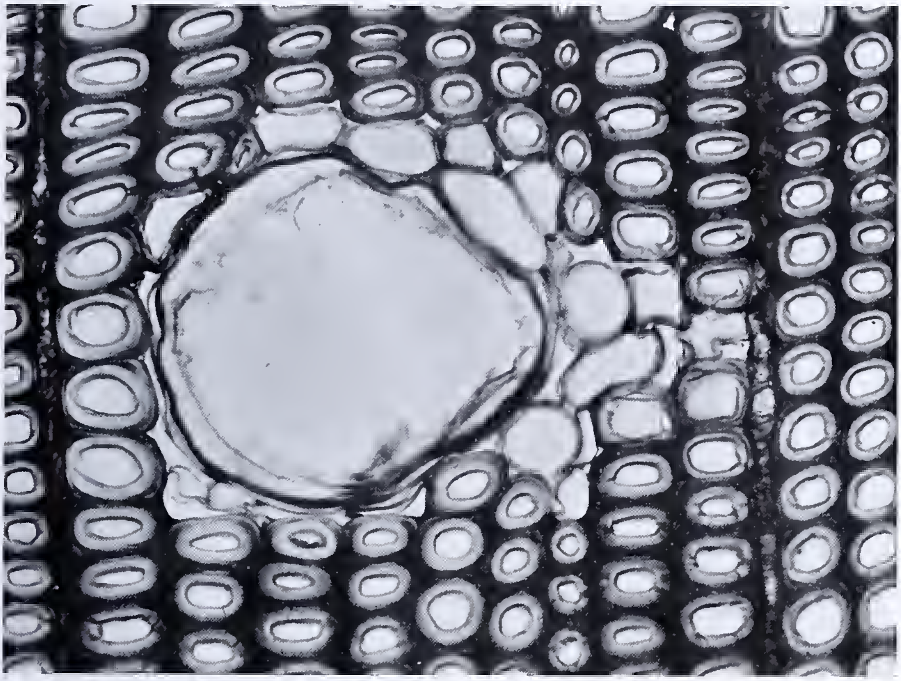


FIG. 36. — Vertical resin duct in *Pinus*. Cross section of *Pinus echinata* (Shortleaf Pine), showing open resin duct with characteristically thin-walled epithelial cells in contrast with the thick-walled Rothholz tracheids. ×250. (Photomicrograph by U. S. Forest Service.)

genera of Leguminosae, all but the three African genera of Dipterocarpaceae, and a very few others.* They are sometimes solitary, but more often in tangential arrangement. Traumatic vertical canals or axial series of cysts have been found in representatives of many families, and are in concentric or tangential rows (Fig. 38). There is lack of uniformity in their origin and development in different species; they may be either *schizogenous*, or *lysigenous*, *i.e.*, resulting from the disintegration or gummosis of the cell walls, or *schizo-lysigenous*, *i.e.*, the canal is first formed by cell separation and subsequently becomes enlarged by gummosis of the tissue adjacent. The final stages of the last

* See *Tropical Woods* 4: 17–20, Dec. 1, 1925.

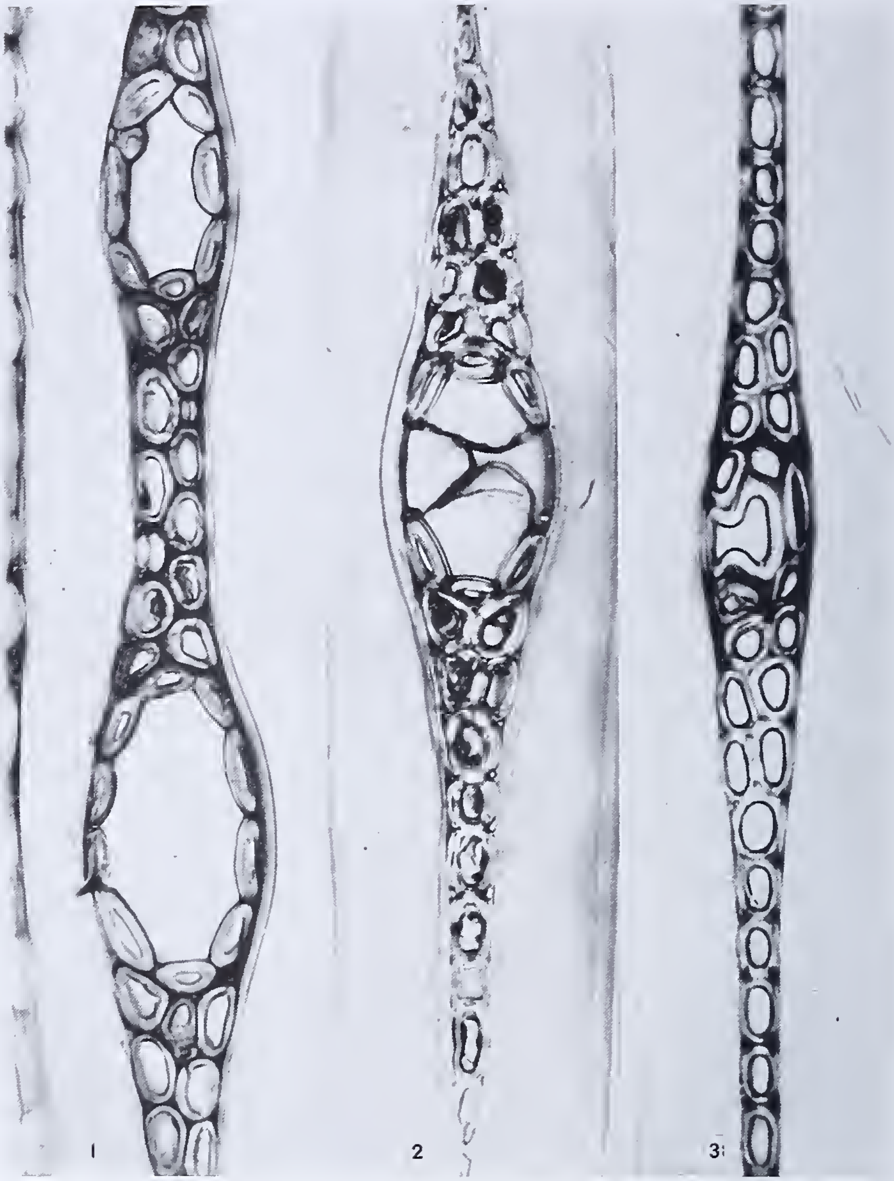


Fig. 37. — Radial resin ducts and tylosoids in *Picea*. ×440. (1) Tangential section of *Picea rubra* (Red Spruce), showing two resin ducts with all epithelial cells thick-walled. (2) Ray of same, showing resin duct closed by proliferations of thin-walled epithelial cells, or tylosoids. (3) Ray of *Picea Engelmannii* (Engelmann Spruce), showing resin duct closed by a tylosoid that has developed a thick secondary wall. (Photomicrographs by U. S. Forest Service.)

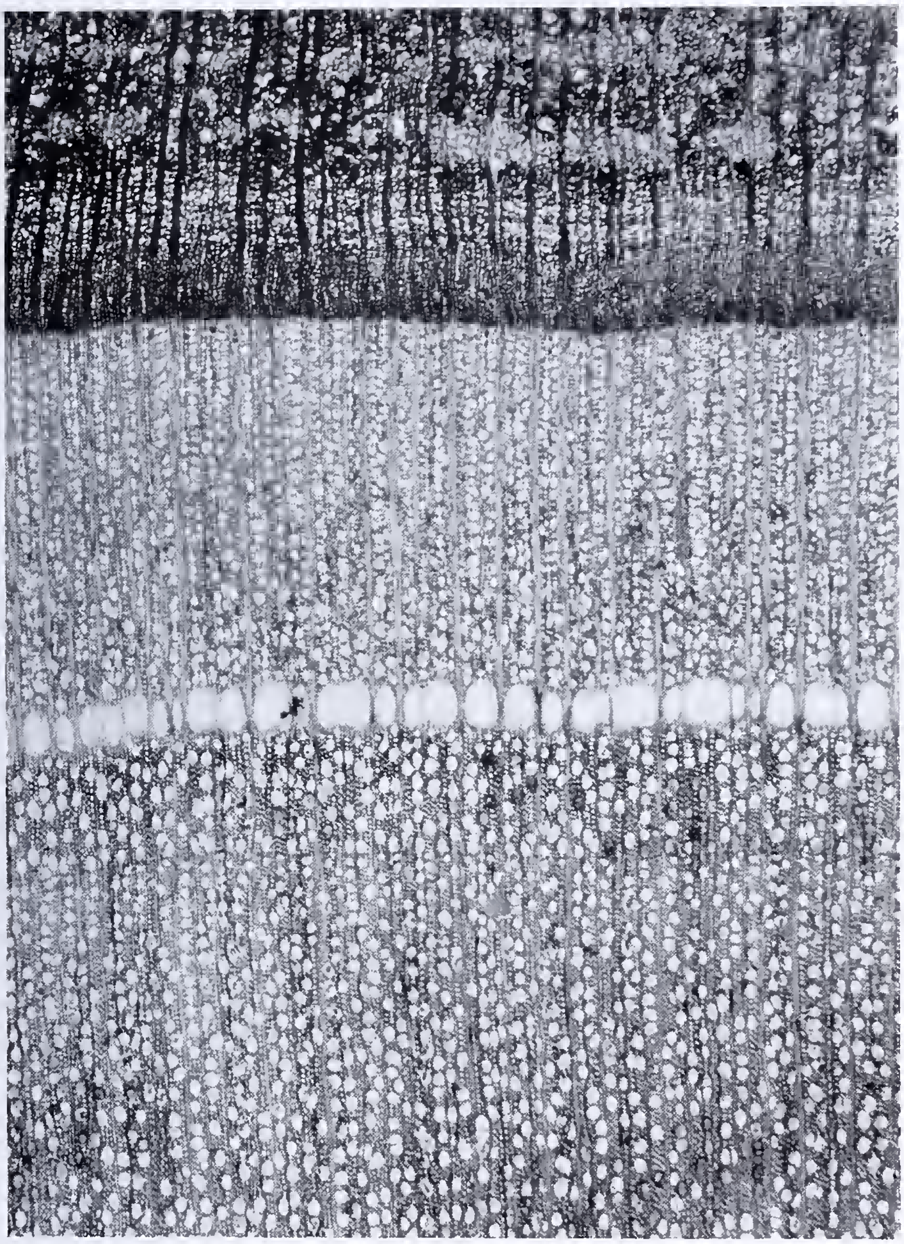


Fig. 38. — Traumatic gum ducts in *Liquidambar styraciflua* (Red Gum): Cross section through inner bark and outer sapwood, showing normal structure except for a uniseriate row of intercellular canals developed in the last growth ring above a cut made through the cambium on May 30 of that year. ×20. (Photomicrograph by U. S. Forest Service.)

two forms usually are not distinguishable. The cells that first surround the vertical canals are parenchymatous, but lysigenous enlargement may effect a change.

Radial gum ducts (Fig. 39) characterize many species of dicotyledonous woods and range in size from minute to large enough to be seen without a lens. Their contents may exude and discolor the wood. If the rays are ordinarily narrow, those with ducts are fusiform as seen in the tangential section; if the rays are wide there is little or no enlargement about the ducts. A single ray may contain one or two, rarely three or four, ducts, and there does not appear to be any regularity as to their location within the ray. When, as is usually the case, the cells about a duct are smaller than the others, the canal is roughly circular or elliptical in section. Sometimes (*e.g.*, certain Araliaceae) the canals appear merely as large intercellular spaces among the ordinary cells. Radial gum ducts, unlike the axial ones, are nearly always of normal occurrence and are commonly connected with vertical ducts or cavities in the cortex and sometimes also in the pith; in a few instances (*e.g.*, *Shorea* spp.) they anastomose with axial canals in the wood.

Lysigenous canals have no true epithelium. In the other ducts the limiting cells may be large or small, and their walls may be of uniform thickness or much thinner in the part facing the cavity. In the radial canals of *Odina wodier* (Fig. 39, No. 3) there is a single distinct and regularly disposed layer of epithelial cells in communication with the cavity by means of large blind pits. Resin ducts may be open or more or less completely filled with solid or liquid material, which often is dark colored.

Another type of intercellular canal occurs in certain tropical woods of a few families, notably Apocynaceae and Euphorbiaceae. These are open and dry, radially elongated spaces, which, in some instances at least, extend from the pith to the cortex. They vary in size from scarcely visible to large openings 1.5 cm. high and 3 mm. wide. Their distribution is irregular in the same specimen, but the large ones often are widely scattered, sometimes being several inches apart vertically, suggesting leaf traces. Their presence provides a valuable diagnostic feature, but their absence from a specimen may not be significant.

In addition to the cysts that are short ducts, there are others that have no tendency to form chains or definite series. *Pitch pockets* are abnormal openings in or between the growth layers of

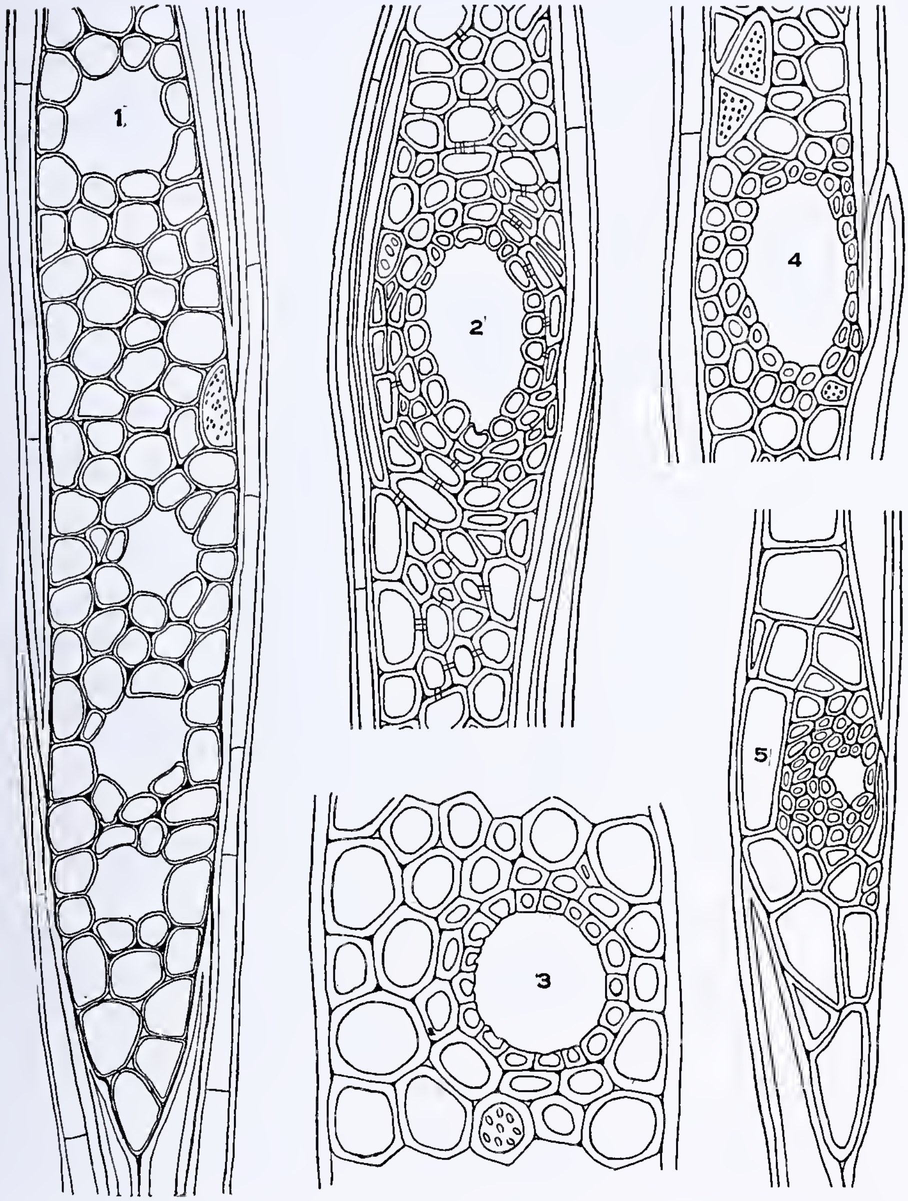


FIG. 39. — Radial gum ducts in various dicotyledonous woods. (1) Four ducts without distinct epithelial layer in ray of *Didymopanax morototoni*, fam. Araliaceae. (2) Single duct within a group of small cells in *Schinopsis Lorentzii* (Quebracho), fam. Anacardiaceae. (3) Cylindrical duct with uniseriate epithelium in *Odina wodier*, fam. Anacardiaceae; the epithelial cells have large blind pits facing the duct. (4) Typical duct in *Santiria nitida*, fam. Burseraceae. (5) Minute duct in a group of many small cells in *Rhus laurina*, fam. Anacardiaceae.

Gymnosperms, which contain more or less resin in either solid or liquid form; they are variable in size and shape, sometimes being very large. Oblate or spheroidal spaces, called *gossypol cavities*, are of occasional occurrence in the xylem as well as the phloem parts of the rays of *Gossypium* and perhaps other Malvaceae. Lysigenous gum cysts are common in the xylem rays of many Myrsinaceae. Laticiferous and tanniniferous tubes are sometimes mistaken for radial ducts, but the cavity of a tube is the lumen of a cell, whereas a duct is an intercellular space.

TABLE XIV

OCCURRENCE OF INTERCELLULAR CANALS IN DICOTYLEDONOUS WOODS

Vertical-Normal

CORNACEAE
- Mastixia

DIPTEROCARPACEAE
- (All but 3 genera)

LEGUMINOSAE
- Copaifera
- Daniella
- Detarium
- Eperua
- Kingiodendron
- Prioria
- Oxystigma
- Sindora

SIMARUBACEAE
- Simaruba

Vertical-Gummosis Type

AMYGDALACEAE
- Amygdalus
- Prunus
- Pygeum

BOMBACACEAE
- Bombacopsis
- Bombax
- Cavanillesia
- Ceiba
- Durio

BORAGINACEAE
- Cordia

COMBRETACEAE
- Terminalia

ELAEAGNACEAE
- Elaeagnus

Vertical-Gummosis Type (Cont.)

ELAEOCARPACEAE
- Elaeocarpus
- Sloanea

HAMAMELIDACEAE
- Altingia
- Liquidambar

LECYTHIDACEAE
- Eschweilera
- Lecythis

LEGUMINOSAE
- Andira
- Berlinia
- Hardwickia
- Herminiera
- Hymenaea
- Macrolobium
- Peltogyne (?)

MALVACEAE
- Hibiscus
- Thespesia

MELIACEAE
- Carapa
- Cedrela
- Entandrophragma
- Khaya
- Melia
- Sandoricum
- Swietenia

MORINGACEAE
- Moringa

MYRTACEAE
- Angophora
- Eucalyptus
- Rhodamnia

Vertical-Gummosis Type (Cont.)

RUTACEAE
- Balfourodendron
- Citrus
- Esenbeckia
- Euxylophora
- Flindersia
- Xanthoxylum

SAPINDACEAE
- Dilodendron

SIMARUBACEAE
- Ailanthus

STERCULIACEAE
- Brachychiton
- Heritiera
- Sterculia
- Tarrietia
- Theobroma

VOCHYSIACEAE
- Qualea
- Vochysia

Radial-Small

AMYGDALACEAE
- Pygeum (?)

ANACARDIACEAE
- Astronium
- Buchanania
- Campnosperma
- Dracontomelum
- Gluta
- Koordersiodendron
- Melanorrhoea

TABLE XIV — (Continued)

Radial-Small (Cont.)	*Radial-Small* (Cont.)	*Radial-Large*
Odina	Santiria	APOCYNACEAE
Parishia	EUPHORBIACEAE	Alstonia
Pistacia	Euphorbia	Aspidosperma
Poupartia	Homalanthus	Couma
Rhus	GUTTIFERAE	Dyera
Schinopsis	Mammea	Lacmellia (?)
Schinus	Ochrocarpus	Lanugia
Spondias	Rheedia	Malouetia
Swintonia	HAMAMELIDACEAE	Plumeria
Tapirira	Altingia	Stemmadenia
ARALIACEAE	Liquidambar (?)	Tabernaemontana
Arthrophyllum	LEGUMINOSAE	Thevetia
Cheirodendron	Herminiera (?)	Zschokkea
Didymopanax	Hardwickia (?)	SOLANACEAE (?)
Gilibertia	LYTHRACEAE	Duckeodendron
Heptapleurum	Crypteronia	EUPHORBIACEAE
Schefflera	MYRTACEAE	Alchornea
Sciadodendron	Eugenia	Croton
BURSERACEAE	Leptospermum	Euphorbia
Boswellia		Mabea
Bursera		Pera
Canarium		Sapium
Elaphrium		LOGANIACEAE
Garuga		Anthocleista
Protium		

STORIED STRUCTURE

Many dicotyledonous woods, notably Leguminosae, are characterized by a storied or tiered arrangement of their elements, which gives rise on the tangential surface to fine horizontal lines or bands commonly called *ripple marks.** These markings may be distinct, indistinct, or invisible to the unaided eye. They usually are seen to better advantage in heartwood than in sapwood unless the heartwood is too heavily infiltrated. Ordinarily a stem must be several years old before the typical storied structure is developed, but sometimes (*e.g.*, in Zygophyllaceae and certain Leguminosae) the stories may be fairly regular in the second annual layer. The number of markings per inch of length varies from as low as 35 in *Bombax* to upward of 300 in *Guaiacum*, but usually is between 75 and 150; there is considerable fluctuation in the same species and in different parts of the same tree.

In the extreme and also the most common form of storied struc-

---

* See *Bulletin Torrey Botanical Club* (New York) 46: 253–273, July 31, 1919. Also *Tropical Woods* 9: 13–18, March 1, 1927.

ture (*e.g.*, in Zygophyllaceae, Bignoniaceae, Leguminosae in large part) the rays, vessel members, tracheids, wood fibers, wood parenchyma strands, and fusiform parenchyma cells are all in horizontal seriation (Fig. 40). The junction of two tiers of wood cells is usually marked by a line varying in appearance and distinctness according to the elements involved in a particular area,

FIG. 40. — Cube of a wood with storied structure. Three photomicrographs of *Dalbergia retusa* (Cocobolo) arranged in their natural positions. Cross section (at the top) shows six solitary pores and one pore multiple of three; narrow rays and fine lines of metatracheal parenchyma crossing them; and darker ground mass composed of libriform fibers. Radial section (at the left) shows an open vessel and a ground mass of libriform fibers and parenchyma strands crossed by the rays. Tangential section (at the right) shows horizontal seriation of the elements, especially the rays, nine tiers or stories being visible; the cross-markings thus produced are commonly known as ripple marks. ×30.

whether fibers with interlacing tips, or vessel members and wood parenchyma cells with abrupt terminations. In some instances, also, the local aggregations of pits in the fiber walls where the

lumina become constricted tend to increase the refraction there and thus make the lines more distinct.

When the rays are all storied they occupy the median portion of each tier, the height of which is usually considerably greater than the height of the rays. Consequently there is room for variation in the height of the rays without interrupting the regularity of the transverse markings. If the rays are in perfect seriation, a section between two tiers would miss them completely. In most instances, however, such a section shows rayless gaps, the width of which depends upon the regularity of the stories.

In some woods with two distinct sizes of rays (*e.g.*, Bombacaceae, Malvaceae, and Sterculiaceae), the small rays are in seriation, but the large ones are not (Fig. 41). In such cases the ripple marks are indistinct except in proper light and may easily be overlooked in casual inspection. Sometimes the markings are plainer without the lens than with it and, because of the very limited field under observation, may not be distinguishable at all under the compound microscope.

Vessel members, vascular tracheids, and parenchyma strands correspond in length to the height of each tier. In a few cases where parenchyma is scanty the vessel members and tracheids (when present) seem to be entirely responsible for the ripple marks (*e.g.*, in *Dalea spinosa*, *Artemisia tridentata*, and *Bigelovia graveolens*). Where the parenchyma is abundant, the component cells of the strands may be uniformly disposed and thus give rise to a secondary seriation which, especially if the cells are large, is readily visible under the lens. In this case the height of the tiers is only a half or a fourth that of the ordinary tiers. In species of *Bombax*, *Ceiba*, and *Heliocarpus* the number of cells to a strand is four; in *Charpentiera*, *Diphysa*, and *Lonchocarpus*, two; in *Gossypium* and *Pterocymbium*, two in the metatracheal and four in the paratracheal. The same structure obtains in some of the finer-textured woods, but the small size of the cells usually renders it indistinct or invisible under the lens.

The wood fibers may or may not show distinct seriation in the tangential section. In all ordinary cases the fibers are much longer than the vessel members or the height of the tiers. Often there is a widened middle portion equal to about one-third of the total length of the fiber and corresponding to the height of the original cambial initial. The attenuated ends of the fibers of one tier glide

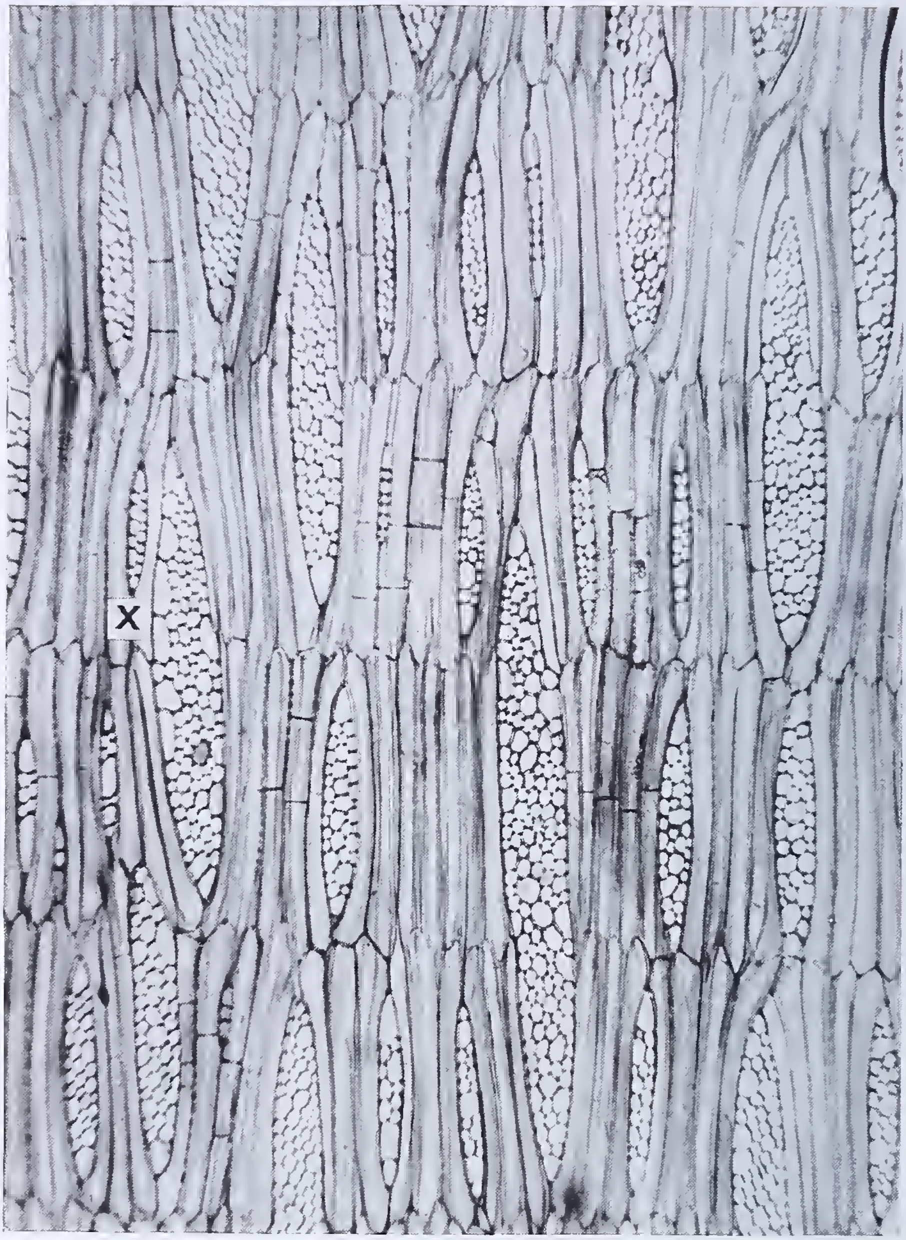


Fig. 41. — Storied arrangement of wood fibers, parenchyma strands, and low rays in *Triplochiton scleroxylon*. The fibers are of a special, non-elongated type frequently found in very soft woods. The large ray at the left shows a layer of sheath cells (X). (Photomicrograph by E. H. B. Boulton.)

during elongation between the fibers of the tiers immediately above and below, and, in consequence, a cross section through the middle portion of a tier will show (under the compound microscope) alternate rows of what appear to be large and small cells, the latter being two to four times as numerous as the large ones, whereas in a section through the junction of two tiers the fibers will appear fewer and of more nearly uniform size. In many woods the fibers exhibit a gradual instead of abrupt diminution in caliber, and the feature just mentioned is absent or indistinct. It may require careful maceration to determine whether or not the fibers are storied, particularly in woods with irregular rays. The septa in septate fibers may give rise to secondary seriation (*e.g.*, *Muntingia*).

The woods with storied structure represent a considerable range of orders and families and, with few exceptions (*e.g.*, *Aesculus*, *Cercis*, *Cytisus*, *Diospyros*, *Tilia*), are of tropical or subtropical origin. The feature is absent from woods with a primitive combination of structural characters, being limited to those with a highly specialized type of structure. The vessel members have abrupt ends and simple perforations, and the pitting is typically alternate instead of scalariform; the wood fibers have simple or indistinctly bordered pits; the vessel-parenchyma pit-pairs are mostly small and half-bordered; and the storied rays are low, narrow, and commonly homogeneous.*

When the elements of a wood are definitely storied it is to be expected that the same arrangement will characterize the secondary phloem. In some instances (*e.g.*, *Dalea spinosa*), the ripple marks are more distinct on the inner face of the bark than on the wood. In *Olneya tesota* the storied structure is plainly evident only in the phloem, where the presence of highly refractive callus on the sieve plates makes the transverse lines distinct.

In examining a specimen for ripple marks it is essential to choose a tangential surface, since the appearance of the radial section often is misleading. The distinctness of the markings on some woods is affected by the angle at which they are viewed. The occurrence of ripple marks in local areas is to be expected in any wood with uniformly low rays.

---

* See *Tropical Woods* 28: 49–50, Dec. 1, 1931.

TABLE XV

Occurrence of "Ripple Marks" in Dicotyledonous Woods

(Asterisk means that not all elements are storied)

Amarantaceae
- Charpentiera*

Bignoniaceae
- Crescentia
- Enallagma
- Paratecoma
- Tabebuia (Tecoma)

Bixaceae
- Bixa
- Maximiliana

Bombacaceae
- Bombacopsis*
- Bombax*
- Camptostemon
- Catostemma*
- Cavanillesia*
- Ceiba*
- Chorisia*
- Cumingia
- Gossampinus*
- Hampea*
- Montezuma*
- Pachira*

Compositae
- Artemisia*
- Baccharis*
- Bigelovia*
- Brachylaena

Dipterocarpaceae
- Balanocarpus (occ.)
- Shorea (occ.)

Ebenaceae
- Diospyros (few spp.)

Elaeocarpaceae
- Muntingia*

Gesneriaceae
- Cyrtandra*

Hippocastanaceae
- Aesculus

Lauraceae
- Cryptocarya (2 spp.)

Leguminosae-Caes.
- Apuleia
- Bauhinia
- Caesalpinia
- Cercis

Legumin.-Caes. (Cont.)
- Daniella
- Dialium
- Dicorynia
- Distemonanthus
- Haematoxylon
- Holocalyx
- Koompassia
- Martiusia
- Melanoxylon
- Mezoneurum*
- Poeppigia
- Pseudocopaiva
- Pterogyne
- Swartzia
- Tamarindus
- Torresia
- Zollernia

Leguminosae-Mim.
- Parkia
- Pithecolobium (occ.)
- Plathymenia
- Wallaceodendron

Leguminosae-Pap.
- Aeschynomene*
- Amphimas
- Andira
- Arthrocarpum
- Baphia
- Belairia
- Bowdichia
- Brya
- Butea
- Canavalia
- Castanospermum
- Centrolobium
- Cytisus*
- Dalbergia
- Dalea
- Derris
- Diphysa*
- Dipteryx
- Erythrina*
- Eysenhardtia
- Genista
- Gliricidia
- Gourliea
- Herminiera*
- Hymenolobium
- Ichthyomethia
- Indigofera
- Inocarpus
- Laburnum*

Legumin.-Pap. (Cont.)
- Lonchocarpus
- Machaerium
- Millettia
- Myrocarpus
- Myrospermum
- Myroxylon
- Olneya*
- Ormosia
- Ougeinia
- Phylloxylon
- Pictetia
- Platycyamus
- Platymiscium
- Platypodium
- Pongamia
- Pterocarpus
- Sophora*
- Sweetia
- Tipuana

Malvaceae
- Abutilon*
- Bastardiopsis*
- Bombycidendron
- Gossypium*
- Hibiscus*
- Thespesia

Meliaceae
- Carapa (occ.)
- Cedrela (occ.)
- Chickrassia (occ.)
- Entandrophragma (occ.)
- Khaya (occ.)
- Swietenia
- Xylocarpus

Moraceae
- Ficus (few spp.)

Moringaceae
- Moringa (occ.)

Myoporaceae
- Eremophylla
- Myoporum (occ.)

Myrsinaceae
- Aegiceras*

Nyctaginaceae
- Pisonia*

Piperaceae
- Piper* (occ.)

TABLE XV — (Continued)

RUTACEAE	SURIANACEAE	TILIACEAE (Cont.)
Chloroxylon	Suriana	Schoutenia*
Esenbeckia (occ.)		Tilia*
	TILIACEAE	
SIMARUBACEAE	Apeiba*	TRIPLOCHITONACEAE
Picraena*	Belotia*	Mansonia
Picrasma	Berrya	Triplochiton*
Simaruba	Carpodiptera*	
	Columbia*	ULMACEAE
STERCULIACEAE	Diplodiscus	Holoptelea
Guazuma*	Goethalsia*	Phyllostylon
Heritiera*	Grewia*	
Kleinhovia	Heliocarpus*	ZYGOPHYLLACEAE
Melochia	Luehea	Bulnesia
Pterocymbium*	Mollia*	Guaiacum
Pterospermum*	Pentace	Larrea
Sterculia*	Pityranthe	Porlieria
Tarrietia*		

Growth Rings

A layer of wood produced during one growing period is termed a **growth layer** or, in cross section, a **growth ring.*** In temperate climates, where there is normally only one growing season a year, the layers and rings are commonly referred to as *annual layers* and *annual rings*, respectively. Interruption of the normal course of growth of a season may result in the formation of a *double* or *multiple annual ring;* one of the zones of growth of such a ring is known as a *false annual ring* (Plate II, Fig. 4). The less dense, larger-celled, first-formed part of a growth layer is the **early wood** or *spring wood;* the denser, smaller-celled, later-formed part is the **late wood** or *summer wood.* The terms spring wood and summer wood are applicable in temperate climates only.

Many tropical woods exhibit zones of growth as a result of local variations in porosity, density, or special arrangement of the elements, but it is rarely possible to determine their relation to definite periods of time. There is as yet no adequate criterion for distinguishing periodic laminations that correspond to whole seasons from multiple layers formed during a single growing period. At present the matter must be left to the judgment of the observer.

In ring-porous woods the growth rings are usually distinct because of the successive development of rows or bands of large pores in alternation with denser layers composed mostly of wood fibers. In diffuse-porous woods, growth rings may be characterized by

* The outer limit or *boundary* of a growth ring should not be confused with the growth ring itself.

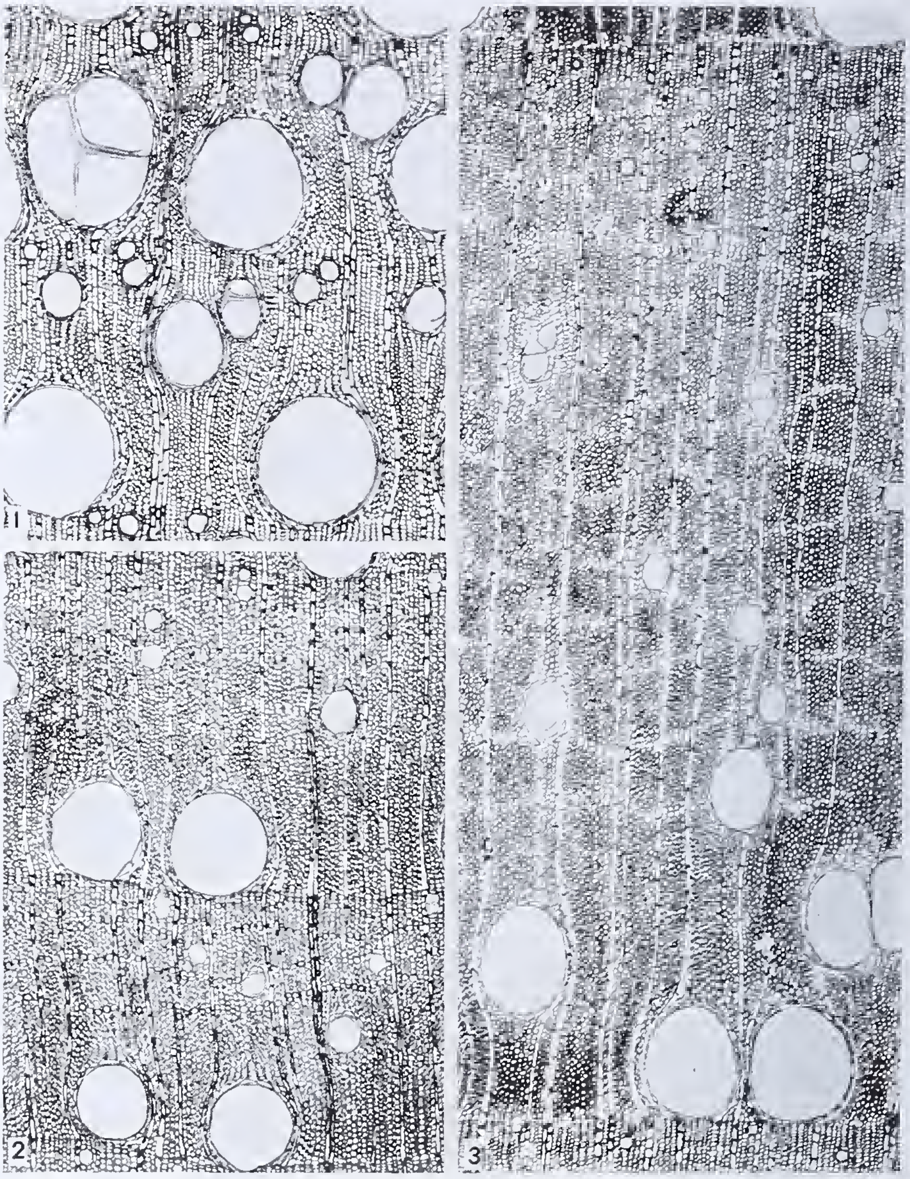


FIG. 42. — Effect of rate of growth on the structure of a ring-porous wood. Three cross sections of *Hicoria*, showing differences in size, relative abundance, and arrangement of the elements. ×45. (Photomicrographs by U. S. Forest Service.)

one or more of the following features: a gradual diminution in size of the pores toward the periphery of the ring; a decided reduction in number of the pores in the late wood; a change in kind of the wood elements (*e.g.*, where the outer layer of late wood consists wholly or chiefly of wood parenchyma or of tracheids); an increase in thickness of the wall or decided flattening of the wood fibers at or near the boundary. In typical Gymnosperms, the transition from open to dense structure may be gradual, as in the Soft Pines, or very abrupt, as in most Hard Pines. Increase in density ordinarily is accompanied by a deepening of the color peculiar to the tissue as a whole. In any case it is the contrast in appearance between the late-formed elements of one season and the first-formed cells of the next that defines the zones of growth.

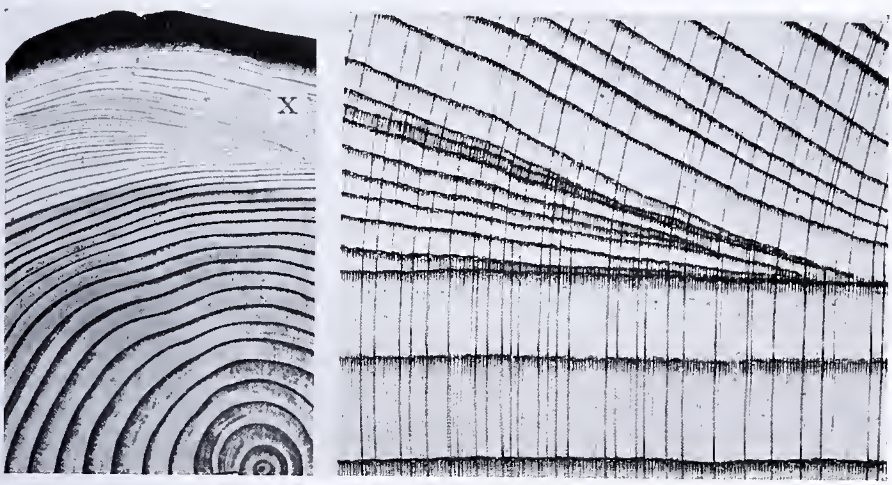


FIG. 43. — Discontinuous growth rings in *Sequoia sempervirens* (Redwood). The photomicrograph at the right is of the area just below X in the photograph of the end of a stem (three-eighths natural size) at the left. (Both pictures by Emanuel Fritz.)

Variation in width of different growth rings is common to all trees, and in healthy individuals is determined by external conditions of light, heat, moisture, and available food supply (Fig. 42). In consequence of unequal acceleration of the growth on different sides, the rings may become undulating, eccentric, or even discontinuous (Fig. 43). The more nearly erect the stem and perfect the crown, the more closely will the center of growth approximate the geometric center of the axis. In some species (*e.g.*, *Carpinus*, *Juniperus*), irregularity of growth causes the trunks to become

fluted or even deeply scalloped. The growth of limbs is commonly eccentric.

The growth rings near the center of a stem generally exhibit considerable difference in structure from those formed later. The elements are usually thinner walled and less densely aggregated, so that the inner core of wood is comparatively soft and weak. In the wood of Dicotyledons the arrangement of the elements, particularly the distribution of the vessels and wood parenchyma, is often decidedly different in the region near the pith from what it is farther out in the stem. On this account the results obtained from the study of herbarium material often are of only limited application to mature specimens.

Sapwood and Heartwood

The histories of the various elements of secondary wood are essentially the same, namely, they are derived from the cambium, increase in size, nearly always form a secondary wall, and sooner or later lose their protoplasts and become mere cell skeletons. The circulation of water and the strengthening of the stem are functions that can be performed by cell skeletons, but the storage and translocation of elaborated food is a vital function of protoplasm. Tracheary elements, therefore, are actually alive only up to the stage when their principal physiological activity begins, whereas a parenchyma cell is physiologically active only so long as it contains living protoplasm, usually a matter of several to many years, although some ray parenchyma cells lose their protoplasts very early.

At first all parts of the woody cylinder are physiologically active, but later some of the cells cease to function, except mechanically, and eventually the stem becomes differentiated into two, often very distinct, regions, namely, the **sapwood**, a layer of variable thickness just inside the bark, and the **heartwood**, a central core of nonliving tissue that formerly was sapwood (Fig. 4, p. 10). The heartwood increases in diameter and volume throughout the life of the tree, whereas the sapwood becomes thinner, though retaining approximately the same volume. In the same species there is a fairly constant relation between the expanse of crown and the volume of sapwood. Rapidly growing trees have a larger proportion of sapwood than those that grow slowly, but in the latter case the number of growth layers in the sapwood is usually greater.

The thickness of sapwood varies widely in different species, in different individuals, in different portions of a single tree, and often on different radii of any particular section. Thin sapwood is characteristic of certain genera, for example *Catalpa, Robinia, Toxylon, Sassafras, Morus, Gymnocladus, Juniperus,* and *Taxus;* in others, such as *Hicoria, Acer, Fraxinus, Celtis,* and *Fagus,* thick sapwood is the rule.

The transition from sapwood to heartwood is not accompanied by any increase in the thickness of the cell walls, but various other changes take place, such as infiltrations of gummy, resinous, and other materials, formation of tyloses, and a more or less pronounced deepening or other modification of the color. As a result of such changes, which, with the exception of tyloses, are not anatomical, heartwood may differ very materially from the sapwood in appearance, density, durability, penetrability, and other properties; in some genera, however, the heartwood is not clearly differentiated (*e.g., Nyssa, Ilex, Celtis, Populus, Salix, Picea, Abies,* and *Tsuga*) and such trees are sometimes referred to as *sapwood* trees. In timbers of the temperate zones, differences in strength of comparable specimens of heartwood and sapwood are negligible.

Heartwood is sometimes formed pathologically in the sapwood as a result of injury to the living cells; it does not differ structurally from ordinary heartwood. Sometimes in the heartwood there are masses or concentric zones that retain the appearance and technical properties of sapwood; they are referred to as **included sapwood.**

Texture, Grain, and Figure

Texture denotes the relative size or quality of the elements of wood; *grain* refers to their structural arrangement.* *Figure* relates to the pattern or design visible on the surface of lumber; it may owe its existence to certain types of grain or to variations in color or to both in combination. Texture and grain are general terms requiring a qualifying adjective to attain specific meaning and are very commonly confused in popular usage.

Texture is generally referred to as fine, medium, coarse, uniform, uneven, smooth, harsh, etc. A wood is *coarse textured* if many of its elements are noticeably large (*e.g., Castanea, Gymnocladus, Sequoia*), and fine textured if the opposite condition prevails (*e.g.,*

* See *Forestry Quarterly* (Ithaca, N. Y.) 9: 1: 22–25, 1911.

Juniperus, Aesculus, Buxus). In the same genus the texture in some species may be fine and in others medium or coarse, and in the same species there may be differences attributable to rate of growth. A wood is of *uniform texture* if its elements exhibit little variation in size (*e.g., Taxodium, Juniperus, Sequoia, Aesculus*); of *uneven texture* if the opposite condition prevails, as in all prominently ring-porous woods (*e.g., Quercus, Castanea, Ulmus, Fraxinus*) and others with decided differences between early and late wood (*e.g., Pinus palustris, P. taeda*, and *Pseudotsuga*) or with distinctly laminated structure (*e.g., Ulmus, Ficus, Apeiba*). *Harsh, smooth,* and *soft texture* are terms applying to the feel, especially of the surface of unfinished lumber, or to the manner in which wood works under tools.

Grain is generally described as fine, coarse, even, uneven, straight, cross, diagonal, spiral, twisted, wavy, curly, feather, roe, mottled, landscape, bird's-eye, gnarly, and silver. *Coarse grain* applies to woods with wide growth layers; *fine grain*, to woods of slow growth; *even* and *uneven*, respectively, to regularity or irregularity of growth. *Straight grain*, as applied to a tree, occurs when the wood elements are parallel to the axis; as applied to a beam, when the radial and tangential planes of structure are parallel to its length. Sawn boards or timbers are often cross grained or diagonal grained even when cut from straight-grained logs, while short straight-grained pieces may be split from spiral-grained trees. When the elements interweave or are not constant in one general direction, wood is also said to be cross grained, though the terms *interlocked grain* and *spiral grain*, respectively, are more appropriate; this condition often does not interfere with tangential splitting. Wood with interlocked fibers is tough and not necessarily weakened, but always tends to warp and twist in seasoning. Examples occur in *Nyssa, Aesculus, Liquidambar*, and *Eucalyptus*.

Figure,* in the sense used in the timber trade, applies only to lumber that exhibits special and attractive designs in grain and (or) color, whereas the wood technologist generally uses the term in a broader sense to include all pattern-like arrangement of the tissues. Thus manufacturers consider Oak lumber figured when radially cut (the rays giving rise to *silver grain*), and plain when

* See *The American Architect* (New York) 111: 2145: 65–72, Jan. 31, 1917; *House and Garden* (New York), Nov. 1917, pp. 24–25; *American Forestry* (Washington, D. C.) 27: 234: 611–617, Oct. 1921.

tangentially cut, although in the latter case the alternation of light late wood and dark early wood may form a conspicuous and attractive pattern. In Gymnosperms with distinct seasonal variations in the growth layers, the pattern of irregular ovals and parabolas on tangentially cut lumber is similar to that of ring-porous Dicotyledons, except that the light areas are early wood and the dark parts late wood (Fig. 44, Nos. 1, 2).

The radial surface of lumber with interlocked grain exhibits alternate lustrous and dark stripes which are changeable with the lighting. In such woods the elements are inclined to the right and left in successive layers of variable width. In many cases, at least, the elements are not arranged in continuous spirals about the tree, but are in waves up and down the trunk. The different angles of inclination of the cells with respect to the source of light give rise to reversible stripes. This type of figure is referred to variously as stripe mottle,* roe grain, ribbon grain, feather stripe, etc. The various forms appear to best advantage in Mahogany (Fig. 45, No. 2).

Wavy grain results when the elements undulate in a regular manner without successive layers crossing. The appearance of the radial surface of wavy-grained lumber is described as *fiddle-back mottle* (Fig. 44, No. 3), owing to the common use of wood with such figure in making the backs of violins. The lustrous and dark areas are reversible as in the case of roe grain, but they are transverse instead of vertical.

In the crotch of a forked tree and at the flare of a root the wood is folded or wrinkled and local deposits of pigment are common. Large stumps of Walnut trees often are used for veneers in cabinet work and for gunstocks. Lumber from the crotch of a Mahogany tree frequently exhibits plume-like "curls" (Fig. 45, No. 1). The term *curly grain* is applied without much discrimination to various irregularities of growth.

Burls† are abnormal growths or excrescences common to almost every species of tree, although only in comparatively few cases (*e.g.*, *Sequoia*, *Juglans*, *Ulmus*, *Betula*, *Erica*) are they of merchantable size and quality. They are formed as the result of some

* The term *mottle* is generally applied to any type of figure in wood that appears on a smooth surface as though in relief. Some of the named forms are plum mottle, landscape mottle, fiddle-back mottle, and bird's-eye mottle.

† See *Hardwood Record* (Chicago), June 25, 1912, pp. 39–42.

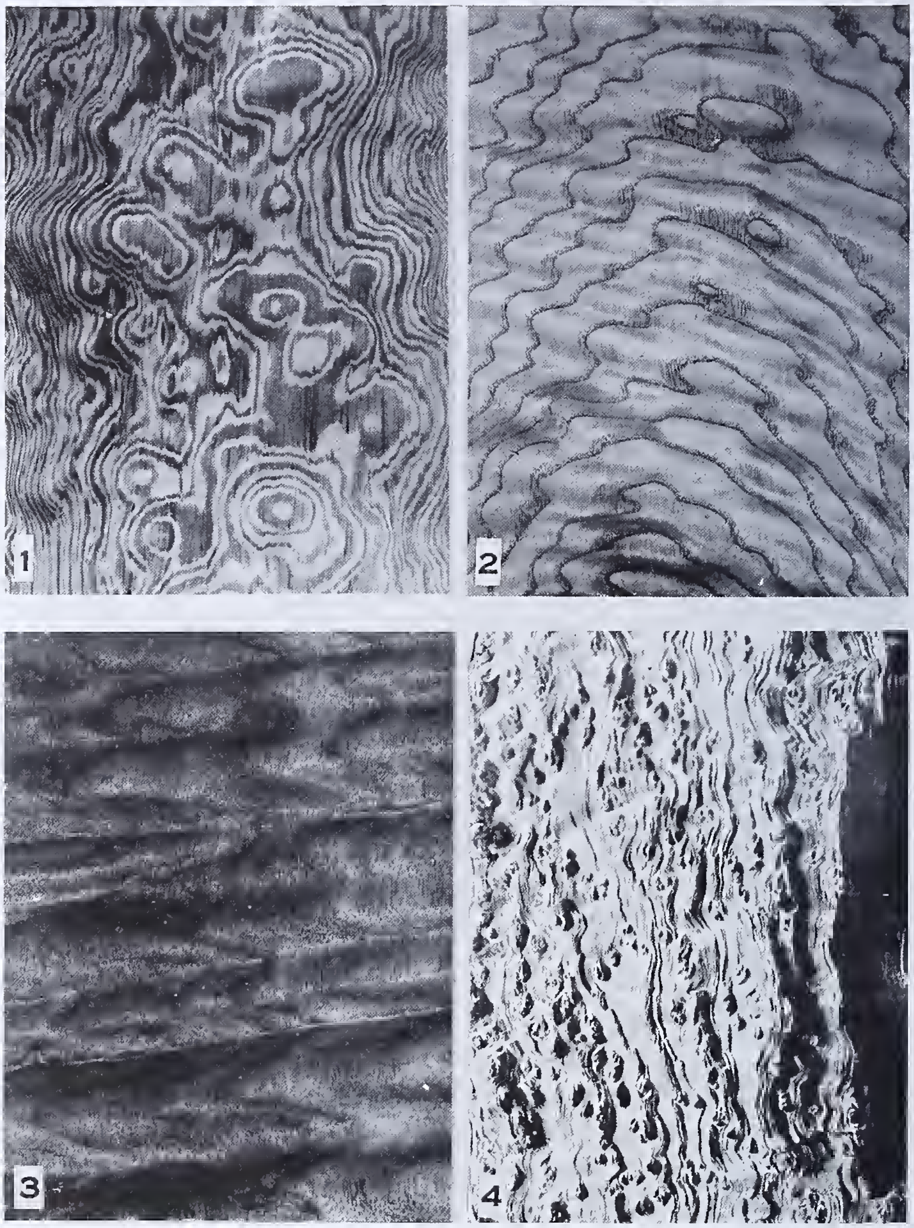


Fig. 44. — Types of figure in wood. One-third natural size. (1) Landscape grain in Southern Yellow Pine. The light areas are early wood, the dark areas late wood; the figure is constant. (2) Wavy grain in White Ash. The light areas are late wood, the wavy dark lines early wood. (3) Fiddleback Black Walnut; the figure is changeable. (4) Split inner surface of a block of bird's-eye Maple showing conical projections toward center of tree.

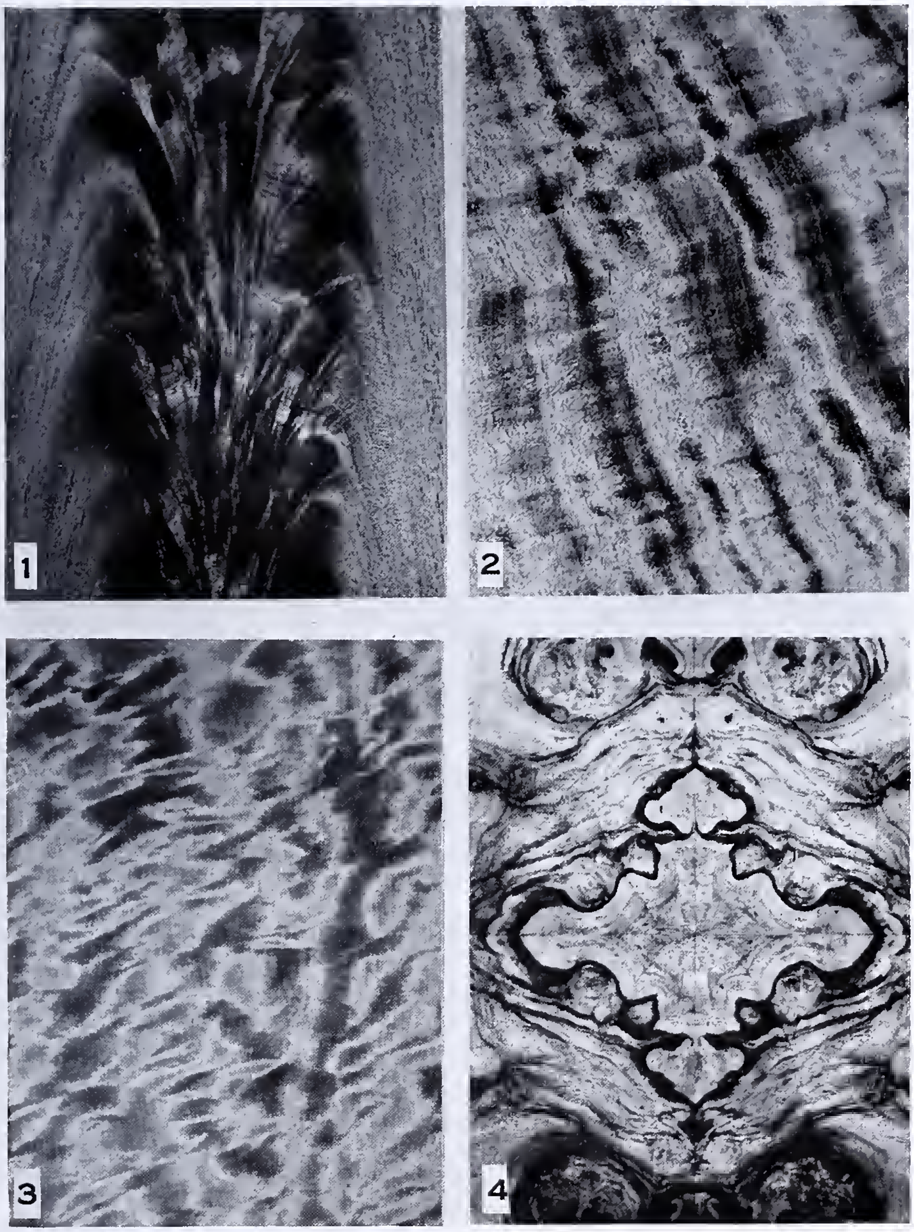


FIG. 45. — Types of figure in wood. One-third natural size. (1) Feather curl in crotch Mahogany. (The picture is inverted to bring out plume effect.) (2) Broken stripe in Mahogany; changeable figure, mostly due to luster. (3) Cloud-like mottle in West Indian Satinwood; changeable figure, mostly due to luster. (4) Panel made from four matched pieces of Walnut burl veneer; constant figure due to variations in color and grain.

injury or irritation that stimulates the growth of dormant buds or occasions the rise of new ones that cannot fully develop but do form a gnarly and interwoven mass of dense woody tissue that often is highly prized for veneers (Fig. 45, No. 4) and articles of turnery. The surface of a burl, inside the bark, is covered with conical projections or spines, each terminated by a bud and having a small central cylinder of pith. When these are cut across, the wood-encircled pith resembles the eye of a bird or small animal.

The figure or mottle usually called *bird's-eye*, however, is of a totally different structure and origin from that of a burl. It is commonest in Hard Maple, and the surface of the wood is pitted and there are spines on the inner bark which project into the pits (Fig. 44, No. 4). According to Hale,* investigations carried out at the Forest Products Laboratories of Canada indicate that these depressions result from temporary local injuries to the cambium by a parasitic fungus.

In Pine, Elm, Douglas Fir, and especially in Sitka Spruce it is not uncommon to find logs with irregular grooves in the wood and corresponding ridges on the inner surface of the bark. In cross section the indentations of the rings are similar to those of bird's-eye, but the markings in tangential section are elongated and often vermiform. Mottled Yellow Poplar lumber sometimes results from injury to the cambium by sap-sucking birds; the markings are usually in tangential rows. In Lodgepole Pine a peculiar dimpling of the wood is produced by resin blisters of the inner bark pressing into the cambial zone.

Color and Luster

The sapwood of a living tree is always light colored, sometimes nearly white, but often with a more or less pronounced yellowish, brownish, or occasionally bluish or pinkish tinge. In most instances the sapwood lumber retains its fresh appearance if properly dried without being attacked by fungi, but sometimes, particularly in certain tropical species, distinct color changes occur upon exposure of the wood to light and air. It is a common practice to treat some kinds of lumber (*e.g.*, Walnut, Apple, Red Gum) with live steam to impart the normal color of the heartwood to the

* Hale, J. D.: *The identification of woods commonly used in Canada.* Bul. 81, Canadian Forest Service, Ottawa, 1932, p. 15.

sapwood. In some dry wood specimens the sapwood is considerably darker than the heartwood, but this condition is a result of *post mortem* changes and is never characteristic of fresh, sound timber. In a few instances (*e.g.*, Barberry, Kentucky Coffee-tree), the natural color of the sapwood is highly characteristic, but ordinarily it is the heartwood that is distinctively colored.

There are many so-called sapwood trees in which the heartwood is light colored and not clearly differentiated, but there are many more in which the heartwood is in very distinct color contrast with the sapwood. The primary colors represented are red, orange, yellow, and violet. There are no naturally bright blue or bright green woods, although there are some with a bluish or greenish hue. Of the intermediate colors, brown is by far the most common. Bright pink is unusual, but is characteristic of a few tropical woods (*e.g.*, *Sickingia*). Jet black is commonly associated with Ebony (*Diospyros* and *Maba*), but most of the Ebony of commerce is variegated or striped.

In many instances heartwood is fairly uniformly colored throughout, but not infrequently there are local variations which occasionally are highly pronounced and distinctive. Many cabinet woods owe their attractiveness to irregular deposits of coloring matter. Sometimes (*e.g.*, Rosewood, Cocobolo, African Zebrawood, Coromandel, figured Red Gum) there are dark brown or blackish zones that appear in section as growth rings, but close examination reveals that they are independent of the seasonal layers. The Guiana Letterwood or Snakewood (*Piratinera*) is characterized by dark streaks that extend radially instead of vertically and appear on the tangential surfaces as hieroglyphics or suggest the markings on a snakeskin.

Exposure to light and air affects the original color of wood, sometimes deepening it, sometimes completely changing it. Brown is fairly stable, red darkens and tends to become reddish brown, pink and orange usually fade, and deep yellow becomes russet and eventually chocolate brown. White Pine changes in time from buff to deep red, especially near the end of an exposed piece of wood. Gray woods are produced by treatment with ammonia fumes. In commercial practice light-colored woods often are dyed or superficially stained in imitation of other woods or to produce special effects. Bright colors can be imparted to sapwood by the injection of dyes into the living tree. Woods containing

tannin are stained blue-black upon contact with iron when wet, or when submerged for a considerable time in water containing iron in solution. Woods free of tannin tend to become gray upon long submergence in water.

The action of fungi is often responsible for special coloration of wood. In this category are the pink stripes in Boxelder, the bright green of Oak sapwood, the dark brown areas of English Oak, and the dull bluish stain in the sapwood of Pine. Fungi are sometimes associated with insects, either incidentally or naturally, as in the case of ambrosia beetles whose galleries are stained by the fungi they cultivate for food. Injuries to the cambium are responsible for local discolorations; for example, the brown streaks so common in Hickory are mostly the result of injury by sap-sucking birds. In general, the more defective the trunk of a tree is, the more highly figured the wood.

It is generally true that depth of color of wood is a criterion of durability. Thus the heartwood of Red Cedar, Redwood, Mesquite, Osage Orange, Black Locust, and Mulberry is dark colored and resistant to decay, whereas that of Willow, Cottonwood, Basswood, Buckeye, Maple, and Tupelo is light colored and perishable. The deeper color of the heartwood is a result of the infiltration or deposition in the cell walls and lumina of gums, resins, pigments, tannin, and other substances that inhibit fungous growth either through their toxic properties or by exclusion of air. In some instances, however (*e.g.*, White and Yellow Cedars, Cypress, Sassafras), the infiltrated substances tend to prevent decay without greatly deepening the color of the heartwood.

Some woods (*e.g.*, Mesquite, Redwood, Black Walnut, and numerous tropical species) impart color to water in which they are soaked; in some cases (*e.g.*, *Pterocarpus* spp.) the aqueous extract is fluorescent. The color of many others can be removed by treatment with NaOH or other chemicals, but often it is necessary to reduce the wood to pulp before it can be bleached. Many tropical woods (*e.g.*, Fustic, Logwood, Brazilwood, Brazilette, Camwood) contain coloring principles of commercial value, though they have been largely superseded by aniline dyes. Of indigenous woods, Osage Orange and several species of *Xanthoxylum* are sometimes employed for this purpose, usually as adulterants of Fustic (*Chlorophora*).

Color is often of great assistance for diagnostic purposes, but

the range of variation and difficulty of description must always be taken into consideration. The character of the demarcation between heartwood and sapwood, whether sharp or gradual, is also an important feature, though usually not exhibited on very small specimens. The chemical nature of the coloring matter in wood affords a promising, but little-explored, field for scientific research.

Luster, or the manner in which light is reflected by the wood elements and their contents, is an important factor in the choice of woods for decorative purposes and is sometimes serviceable in identification. Luster has depth, whereas *gloss* is entirely superficial and can be imparted to any fine-textured wood by polishing. The finest cabinet woods, regardless of color (unless jet black), are characterized by a golden luster that appears to glow beneath the surface. Luster is affected by the angle at which the light is reflected and is responsible for the changeable effects in certain types of figure (*e.g.*, roe grain, fiddle-back mottle). Some woods, especially those with considerable parenchyma, may appear dull when held in one position and lustrous in another. The presence of oily and waxy substances may reduce or destroy the natural luster, at the same time adding to the ease with which the wood is polished. Among the families noted for lustrous woods are the Lauraceae, Rutaceae, Leguminosae, Moraceae, Meliaceae, and Anacardiaceae.

Scent and Taste

The scent of wood* depends upon volatile chemical compounds which form no part of the wood itself, and ordinarily is more pronounced in heartwood than in sapwood. It is also greater in wood in a green condition than when seasoned, more evident on moist surfaces than on dry. Every wood when fresh possesses in some degree a characteristic scent, although in a great many instances it is so weak or fleeting that it escapes notice. Upon exposure, wood gradually loses its scent, in some cases completely, in others only superficially. Woods deriving their odors from the presence of ethereal oils, as in many Cedars, apparently may be kept indefinitely and still emit their characteristic odors when a fresh surface is exposed.

Upon exposure to the air for a short time some green woods

* See *American Forestry* (Washington, D. C.) 26: 665–672, Nov. 1920.

(*e.g.*, Oak) acquire a disagreeable, soured odor, probably due to the decomposition of certain organic compounds. Woods in process of decay emit various odors, sometimes very disagreeable (*e.g.*, Cottonwood), sometimes not unpleasant (*e.g.*, Oak), but always different from the characteristic scent of the sound wood.

Occasionally the fumes of burning wood are characteristic. Resinous woods, such as Hard Pine, give off an odor of tar. The woods of Eastern Red Cedar and Port Orford Cedar burn with a pungent, spicy scent, giving the latter species a special value for matchsticks. The woods of *Cercidium* and *Parkinsonia* give off very penetrating, disagreeable fumes when burned, reducing materially their desirability for fuel.

The scent of certain woods renders them commercially valuable. Cigars are believed to be improved by being kept in Spanish Cedar (*Cedrela*) boxes. The scent of Cedar woods apparently is repellent to moths and other insects, thus making the lumber desirable for cabinets, wardrobes, chests, and drawers where furs and woolen clothes are kept, although loss of scent from the exposed surfaces soon seriously impairs the efficiency of the material. Highly scented wood is undesirable for some purposes, especially receptacles for wines, liquors, drinking water, and oils, meats, fish, butter, and other foodstuffs that are likely to be tainted.

Although scent is often a valuable aid to the identification of wood, its utility is lessened by the difficulty and often the impossibility of describing it so that another person can recognize it. Such descriptions are necessarily limited to comparisons with well-known scents, and these are usually inadequate. Pine has a resinous scent, and that of the Sugar Pine is rather sweetish. Many woods are called Cedars because they have the characteristic spicy scent of *Cedrus* and *Juniperus*. Port Orford Cedar has an agreeable pungent odor, but that of the Nootka Cypress is disagreeable. Dark-colored, waxy specimens of Bald Cypress (*Taxodium*) smell rancid; Catalpa heartwood suggests kerosene; *Viburnum* and *Gustavia* are obnoxious. The tropical woods best known for their fragrance are mostly members of the families Lauraceae, Santalaceae, Leguminosae, and Meliaceae. Some of the woods owing their names to their olfactory effects are Rosewood, (Australian) Violet Wood and Raspberry Jam Wood, (Brazilian) Clovewood and Garlic Wood, (South African) Stinkwood and Sneezewood, and California Pepperwood. Possession

of a fragrant scent is indicative of a wood suitable for cabinet work and resistant to fungi and insects.

Taste is frequently helpful in identifying woods, although like odor it cannot be described with accuracy. Wood substance, being insoluble in water or weak alkaline solutions, is tasteless, hence the characteristic taste of certain woods is attributable to soluble deposits and infiltrates. The flavor of wood is more pronounced in fresh material than in dry, and not infrequently is more distinct in sapwood than in heartwood, presumably because there the substances tasted are in solution or in more readily soluble form. The woods with most pronounced taste belong mostly to the families Coniferae, Lauraceae, Simarubaceae, and Leguminosae.

Density and Specific Gravity

The density of wood, *i.e.*, the ratio of the mass of wood substance to its bulk, varies widely in different species, in different individuals, and even in different parts of the same tree. The volume of a particular block of wood is affected by the amount of hygroscopic moisture it contains, being smallest when perfectly dry and maximum when the cell walls are saturated. Any wood is at its greatest actual density when it is absolutely dry, though its relative density, or specific gravity,* usually is least at that point.

The specific gravity of wood substance has been variously calculated to be between 1.40 and 1.62. Assuming a value of 1.55, the weight of a solid block of dry wood substance would be about 97 pounds per cubic foot. The densest wood tested by the author was of *Krugiodendron ferreum* (Vahl) Urb., a small tree known as Palo Diablo in Cuba, Black Ironwood in southern Florida, and Axemaster in British Honduras; the specific gravity of two thoroughly air-dry specimens was 1.42, weight nearly 89 pounds per cubic foot. The second densest was Letterwood (*Piratinera guianensis* Aubl.) from Dutch Guiana, its specific gravity being

* The specific gravity of a wood sample is the ratio of its weight to that of an equal volume of water. For accurate determinations the water should be pure and at the temperature of its greatest density, namely, 4° C. (39.2° F.). To convert specific gravity of a wood to weight per cubic foot, multiply by 62.43, the weight of a cubic foot of water. Conversely, dividing the weight in pounds by that figure will give the specific gravity.

1.365 at 8.3 moisture content, and 1.363 absolutely dry.* The heaviest well-known timber of commerce is Lignum-vitae (*Guaiacum* spp.) of the West Indies and Central America, with a specific gravity range of 1.15–1.33, average about 1.25, or 78 pounds per cubic foot. These values are nearly the same as for Quebracho (*Schinopsis* spp.), the tanwood of the Gran Chaco of South America. In all the above examples, the values apply only to heartwood, which owes a considerable part of its weight to natural infiltrations of gums, resins, and other materials. The specific gravity of absolutely dry sapwood very rarely reaches unity; the highest value determined by the author was for a thoroughly air-dry specimen of Letterwood, as follows: outer half, 0.991; inner half, 1.103; heartwood, 1.348.†

The lightest woods known are as follows: *Aeschynomene hispida* Willd. of Cuba, specific gravity 0.044, weight 2.75 pounds per cubic foot; *Alstonia spathulata* Bl. of Dutch East Indies, 0.058 or 3.6 pounds; and *Cavanillesia* spp. of Panama and Brazil, 0.103–0.106 or 6.4–6.6 pounds.‡ The lightest commercial timber is Balsa (*Ochroma* spp.) of Ecuador and Central America, the most desirable grade weighing 7–9 pounds per cubic foot. The lightest wood in the United States is Corkwood (*Leitneria floridana* Chapm.), its specific gravity being 0.21 for the stem and 0.15 for the root. Other exceptionally light woods are obtained from the enlarged bases of certain kinds of Tupelo (*Nyssa* spp.) and the "knees" (pneumatophores) of Bald Cypress (*Taxodium distichum*).

The specific gravity of a wood specimen is very materially affected by the moisture content. Some woods that are of light weight when dry contain so much moisture when freshly cut from the living tree that the logs will not float. The lightest woods will acquire a specific gravity greater than 1.00 if all the air in them is replaced by water. The weight of wood is accordingly of little significance unless the approximate moisture content is known.

In practice there are three general methods of calculating specific gravity: (*a*) both volume and weight of the test specimen are

---

* For further information on these two woods see *Tropical Woods* 6: 5–11, June 1, 1926; 8: 13–15, Dec. 1, 1926.

† For report on last three woods mentioned, see *Timbers of Tropical America*, pp. 134, 314, and 391.

‡ See *Tropical Woods* 37: 52–53, March 1, 1934.

obtained after all the moisture has been removed by drying in an oven at a temperature of 100° C. (212° F.), the boiling point of water; (*b*) both volume and weight of the specimen are obtained when it is air dry; (*c*) the volume is measured when the specimen is in any desired condition, as fresh, soaked, air dry, etc., and the weight taken after oven-drying. The last method is used by the U. S. Forest Service in studying the relation of specific gravity to the mechanical properties of wood, but inasmuch as the test specimen shrinks in drying, the figure obtained is not the true specific gravity of the oven-dry wood.

The actual density of wood depends upon the mass of the cell walls. Since the late wood of a growth layer is usually considerably denser than the early wood, the larger the proportion of late wood the greater the density of the wood as a whole. Density can be judged by visual inspection, and timbers for structural purposes are often classified on a basis of the relative proportions of early and late wood. Within a genus, density is often more important than species in determining the suitability of timber for certain uses. For this reason trade names for timber cannot always be correlated with the names of the trees.

Density is a factor of importance in the identification of woods, but, like size of elements, it is affected by conditions of growth and is never a constant quantity. The single value often assigned to a species is usually the average of many determinations and is applicable in only a general way. A wood with a specific gravity less than 0.50 is considered light; 0.50–0.70, moderately light to moderately heavy; above 0.70, heavy. From an investigation of 429 North American species, as published in the report of the Tenth Census of the United States, the specific-gravity values of 242 species, including most of the commercial timbers, lie between 0.45 and 0.75. The popular belief that tropical timbers are all hard and heavy is erroneous, since both the lightest and the heaviest woods known are of tropical origin. In general, the proportionate number of species represented in the three classes of woods, light, medium, and heavy, is about the same for the tropics as for the temperate zones.

Woods with Anomalous Structure

The stems of some dicotyledonous trees and shrubs and many lianas exhibit various departures from the typical arrangement of plant tissues. The six principal types of anomalous structure, as classified and described by Solereder,* are *internal phloem; included phloem;* successive development of secondary groups of wood and phloem; compound and divided xylem masses; unequal thickening of the xylem mass; and cleavage of the xylem mass.

Fig. 46. — Island type of included phloem. Cross section of *Neea amplifolia,* showing spaces left after the disintegration of the phloem. The islands have a definite arrangement with respect to one another and to the pore chains. ×17.

Internal phloem (also called *intraxylary phloem*) is primary phloem situated internally to the primary xylem. It either forms a layer at the margin of the pith or appears as isolated strands of varying size in the pith. It is an important diagnostic feature that can be employed in the study of herbarium specimens.

---

* Solereder, Hans: *Systematic anatomy of the Dicotyledons.* (Translated by Boodle and Fritsch.) London, 1908, pp. 1159–1167. (Much of the material for Table XVI is from this source.)

Included phloem (also called *interxylary phloem*) is a term applied to strands or layers of phloem situated within the body of the woody cylinder. With respect to origin, included phloem is of two principal types, though they are not always distinguishable after maturity. It may be differentiated from groups of phloem mother cells given off by the cambium *internally*, along with xylem mother cells; or phloem arising in the normal manner may become inclosed as the result of the development of a new cambial zone in the parenchymatous tissue to the outside of the older one.

The appearance of the cross section of a wood with included phloem is usually distinctive. There are various types of arrange-

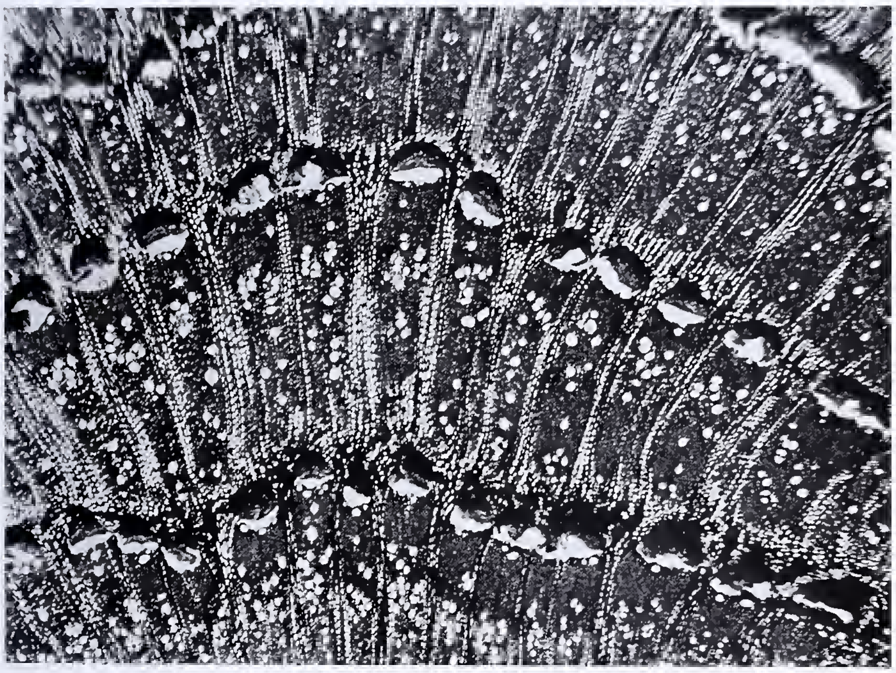


Fig. 47. — Band type of included phloem. Cross section of *Forchhammeria longifolia*, showing concentric series of partially disintegrated strands of phloem in association with bands and rays of conjunctive tissue. ×25.

ment, but for convenience they may be reduced to two, namely, islands and bands. The islands may be round or tangentially flattened, scattered or close together, irregularly or uniformly disposed. In some instances they bear no definite relation to the pores, in others they are located at the end of a chain or group. The bands vary in width, spacing, and regularity. In many woods

(*e.g.*, *Avicennia*, Phytolaccaceae, Menispermaceae) the phloem is associated with a special type of parenchyma, called **conjunctive tissue**, which forms concentric and anastomosing layers and heavy rays that divide the woody cylinder into many vascular bundles. In other woods (*e.g.*, certain Leguminosae) the bands are wide apart and are without radial conjunctive tissue. There are various irregularities and intermediate forms.

Included phloem provides an important diagnostic feature, but in some cases it may be absent from young stems that would later develop it, or its occurrence in older stems may be sporadic. In general, however, it is a dependable character. Many lianas have included phloem.

The types of anomalous structure other than internal and included phloem are mostly confined to lianas. These woody climbers comprise an interesting and highly specialized group of plants, many of which are still very poorly known.

TABLE XVI

OCCURRENCE OF INCLUDED PHLOEM IN DICOTYLEDONOUS STEMS

Band Type

AMARANTACEAE
All (?) genera

AVICENNIACEAE
Avicennia

BUXACEAE
Simmondsia

CAPPARIDACEAE
Cadaba
Forchhammeria
Maerua
Niebuhria
Roydsia

CHENOPODIACEAE
Atriplex
Eurotia
Grayia
Haloxylon
Suaeda

DILLENIACEAE
Doliocarpus

LEGUMINOSAE
Dalbergia
Machaerium
Pueraria
Spatholobus
Wistaria

MENISPERMACEAE
Abuta
Anomospermum
Chondrodendron
Cocculus
Disciphania
Hyperbaena
Pachygone
Pericampylus
Tiliacora

PHYTOLACCACEAE
Agdestis

Band Type (Cont.)

PHYTOLACCACEAE (Cont.)
Barbeuia
Ercilla
Gallesia
Phytolacca
Rhabdodendron
Seguieria

POLYGALACEAE
Bredemeyera
Comesperma
Moutabea
Securidaca

PLUMBAGINACEAE
Acantholimon
Aegialitis
Limoniastrum

Island Type

APOCYNACEAE
Lyonsia

COMBRETACEAE
Calycopteris
Combretum
Guiera

HIPPOCRATEACEAE
Salacia

HYPERICACEAE
Endodesmia

ICACINACEAE
Chlamydocarya
Sarcostigma

LOGANIACEAE
Antonia
Bonyunia
Logania
Norrisia
Strychnos

Island Type (Cont.)

MELASTOMACEAE
Kibessia
Lijndenia
Memecylon
Mouriria
Olisbea
Pternandra

NYCTAGINACEAE
Bougainvillea
Calpidia
Colignonia
Neea
Pisonia
Torrubia

ONAGRACEAE
Epilobium
Oenothera

SALVADORACEAE
Dobera
Platymitium
Salvadora

THYMELAEACEAE
Aquilaria
Brachythalamus
Gyrinops
Gyrinopsis
Linostoma
Lophostoma
Synaptolepis

URTICACEAE
Gyrotaenia
Laportea
Myriocarpa
Urera

VOCHYSIACEAE
Erisma
Erismadelphus

PART II

TIMBERS OF TEMPERATE NORTH AMERICA

Introduction

This part is concerned primarily with the identification of the economic woods of the United States and Canada. The structural and physical characteristics of woods discussed in Part I are made the basis for a descriptive key to 14 genera and 28 specific groups of Gymnosperms, and 37 genera and 52 specific groups of Dicotyledons, a total of 80 different kinds of woods. Each specific group includes from one to several botanical species, some of which can be further differentiated. In general, however, it is at present unsafe to depend on the characters of the wood alone for the separation of closely related botanical species.

The key is designed not only to aid in the identification of unknown specimens of woods, but also to guide the student in comparative work on known specimens. The classification as a whole is artificial in respect to the natural relationships of the trees, but effort has been made to group together the woods that are most nearly alike in appearance, properties, and uses.

So far as is considered practicable, the major distinctions in the key are based on features that are discernible without other mechanical aids than a sharp knife and a simple lens magnifying 10 to 15 diameters. In preparing a specimen for careful examination, either with or without a lens, it is essential that a smoothly cut surface be obtained. Cross sections are, as a rule, the most valuable for comparative study of the gross anatomy, but they are also the most difficult to cut smoothly. If the knife used is not sharp, the cut will rough and the details of structures will be obscured.

The histological features, which usually are not visible without a compound microscope, are indicated in the key by smaller type. Sections for immediate use can be cut free-hand with a sharp pocket-knife or razor, and mounted in water. It is not essential that such sections be of uniform thickness, since a thin edge will

usually exhibit the essential details. Much better results, of course, can be obtained by the use of a simple microtome, and for fine work the best of apparatus and a training in microtechnic are required. Free-hand sections, however, are sufficient for the full use of the key by anyone familiar with wood anatomy.

The scientific names given preference are those adopted as standard for the U. S. Forest Service; and the common names, for the most part, are those used in the timber trade. The latter often are not the same as the tree names, which vary in different parts of the country.

The purpose of identification is not only to name a specimen, but also to make available the information that is associated with the name. The small numerals following the names in the key refer to " Notes and references pertaining to the trees and their utilization " on pp. 130–178. Therein are short accounts of the size, distribution, and relationships of the trees, and the properties, principal uses, and commercial importance of their timber. Attempt is also made to clarify the nomenclature. Most of the references are to publications of interest to lumbermen, wood-users, and foresters rather than to botanists, who, presumably, are already familiar with the literature in their own field.

DESCRIPTIVE KEY TO THE TIMBERS OF TEMPERATE NORTH AMERICA

I. Gymnosperms, Conifers, or Softwoods. (For II, see p. 118.)

Vessels absent. Vertical elements mostly or exclusively tracheids, arranged in definite radial rows; barely visible under lens. Wood parenchyma present or absent; sometimes in distinctly zonate arrangement. Vertical and radial intercellular canals (resin ducts) present or absent. Rays very fine, scarcely visible on cross sections without lens. Growth layers usually distinct because of the abrupt change in density and in color from the late wood of one year's growth to the early wood of the next. Scent and taste often characteristic.

A Vertical resin ducts always present, occurring singly or in small tangential groups; sometimes also in arcs as a result of injury. Radial resin ducts always present in some of the rays, giving them a fusiform appearance in tangential section. Ray tracheids always present. (For **B**, see p. 114.)

a Vertical resin ducts comparatively large, plainly visible without lens; numerous; mostly solitary. Heartwood usually clearly defined and with distinctive resinous scent. Epithelial cells all thin walled, large. Normal ducts of fairly uniform diameter throughout their length. Thin-walled tylosoids common. Isolated wood parenchyma strands absent. Tracheids without spiral thickenings. Ray tracheids comparatively large and numerous, occurring in one to several marginal rows and frequently interspersed in high rays, and often composing entire low rays; upper and lower walls uniformly or very irregularly thickened. Ray parenchyma cells with numerous pits in upper, lower, and end walls; blind pits common; pits in lateral walls large to small, one to several in each cross-field of the early wood, the complementary pits in the vertical tracheids either simple or bordered. (For **b**, see p. 113.) **Pine.**[1]

a[1] Late wood not sharply defined. Texture uniform. Ray tracheids with upper and lower walls uniformly thickened, or smooth. Tangential walls of the late-wood tracheids pitted.

a[2] Wood soft, straight grained. Heartwood distinct. Texture rather fine to coarse. Ray parenchyma cells with 1 or 2 large rounded or squarish pits in each cross-field of the early wood, the complementary pits in the vertical tracheids simple. **White Pine Group.**[2]

a[3] Texture rather fine. Luster high, silky. Color light straw or creamy white to reddish brown, more pronounced in late wood and deepening upon exposure to light. Resin ducts distinct, especially so in wide growth rings, appearing on longitudinal surface as straw-colored or light brown lines. No sugary exudations. Resinous scent mild. Sp. gr. 0.35–0.43. **Northern White Pine,** *Pinus strobus* L.[3]; **Western** or **Idaho White Pine,** *P. monticola* Dougl.[4]

b[3] Texture coarse. Luster low. Color yellowish white to pale brown, never deeply reddish; brown stain common. Resin ducts conspicuous, usually dark colored. Sugary exudations common on fresh lumber. Resinous scent pronounced Sp. gr. 0.32–0.40. **Sugar Pine,** *P. Lambertiana* Dougl.[5]

b² Wood rather hard, cross grained. Texture fine. Heartwood yellowish, not very distinct from sapwood. Scent suggesting beeswax. Sp. gr. 0.45–0.67. Ray parenchyma cells with 3 to 6 small lenticular pits in each cross-field of the early wood, the complementary pits in the vertical tracheids bordered. **Piñon**, *P. edulis* Engelm.[6]

b¹ Late wood distinct because of much greater density, usually with abrupt transition from early wood. Texture uneven. Heartwood very distinct, often highly resinous. Ray tracheids, which often predominate in ray, with upper and lower walls very irregularly thickened, dentate to reticulate. Tangential walls of the late-wood tracheids not pitted.

a² Ray parenchyma cells in early wood with 1 or 2 large rounded or squarish pits in each cross-field, the complementary pits in the vertical tracheids simple. Wood rather light and soft, variable, fairly strong, medium textured; heartwood reddish brown, not highly resinous. Sp. gr. 0.42–0.54. **Norway Pine**, *P. resinosa* Ait.[7]

b² Ray parenchyma cells in early wood with 3 to 6 (occasionally more) small, irregular pits in each cross-field, the complementary pits in the vertical tracheids usually simple.

a³ Wood variable from light and soft to moderately heavy and hard.

a⁴ Wood fairly uniform, soft, mostly fine grained; heartwood pale brown, not highly resinous. Sp. gr. 0.35–0.47. Tangential surface with many shallow indentations produced by resin cavities in inner bark. **Lodgepole Pine**, *P. contorta* Loud.[8]

b⁴ Wood variable from light, soft, and fine textured to fairly heavy, hard, and coarse textured; heartwood reddish brown, sometimes highly resinous; sapwood of old trees nearly white, non-resinous. Sp. gr. 0.39–0.60. Indentations only occasionally present on tangential surface. **Ponderosa Pine**, *P. ponderosa* Laws.[9]

b³ Wood variable from moderately to extremely heavy and hard. **Southern Yellow Pine Group.**[10]

a⁴ Wood very dense and resinous, rather fine grained, with large proportions of sharply defined late wood. (Commercial) **Longleaf Pine,** *P. palustris* Mill.[11]

b⁴ Wood usually moderately dense and resinous, fine to coarse grained, with late wood narrow or, if wide, not compact. (Commercial) **Shortleaf Pine,** *P. echinata* Mill.[12]

b Vertical resin ducts medium-sized and fairly distinct to very small and invisible without lens; rather numerous to very few; occurring singly or in small tangential groups. Heartwood distinct to indistinct; with or without distinctive scent. Epithelial cells mostly thick walled, small. Normal ducts constricted at intervals, appearing as vertical series of cysts. Tylosoids uncommon, sometimes thick walled. Isolated wood parenchyma cells occasionally present, not abundant. Tracheids with or without spiral thickenings. Ray tracheids small and few, usually in single marginal rows; sometimes with minute spiral thickenings, but never heavily sculptured. Ray parenchyma cells thick walled, with numerous pits in upper, lower, and end walls; blind pits common; pits in lateral walls small, lenticular to slit-like, diagonal, 2 to 6 (sometimes more) in each cross-field of the early wood, the complementary pits in the vertical tracheids bordered.

a¹ Tracheids (at least in early wood) with spiral thickenings. Wood variable from pinkish yellow, fine grained, fairly uniform textured, and moderately light and soft, to reddish brown, coarse grained, uneven textured, with open and weak early wood and very dense late wood. Sp. gr. 0.39–0.68, mostly 0.45–0.55. Heartwood clearly defined; not highly resinous. Resin ducts rather numerous and distinct. **Douglas Fir,** *Pseudotsuga taxifolia* Britt.[13]

b¹ Tracheids without spiral thickenings. Resin ducts few and not distinct; appearing in late wood commonly as whitish dots, under lens.

a² Sapwood sharply defined. Wood variable, but mostly hard and heavy, with distinct contrast between early and late wood. Not highly lustrous.

a³ Heartwood red to reddish brown, sometimes highly resinous. Sapwood thin, white. Tex-

ture coarse and harsh. Grain fine, uniform, fairly straight. Sp. gr. 0.59–0.83, mostly 0.60–0.70. **Western Larch**, *Larix occidentalis* Nutt.[14]

b³ Heartwood yellowish brown, not reddish, not highly resinous. Sapwood rather thin, pale brownish. Texture medium. Grain usually coarse and more irregular. Sp. gr. 0.54–0.78, mostly 0.55–0.65. **Tamarack**, *L. laricina* (DuRoi) Koch.[15]

b² Sapwood not sharply defined. Wood variable from light and soft to moderately so, with slight to decided contrast between early and late wood; not resinous. Texture fine. Luster high, satiny, dappled on tangential surface. **Spruce.**

a³ Heartwood pale brownish or nearly white, uniform. Resin ducts usually invisible without lens. Sp. gr. 0.31–0.53, mostly 0.35–0.45. **Eastern Spruce**, *Picea rubra* Link, *P. glauca* (Moench) Voss, and *P. mariana* Mill.[16]; **Engelmann Spruce**, *P. Engelmannii* Engelm.[17]

b³ Heartwood reddish or pinkish, with gradual transition from sapwood. Resin ducts fairly distinct. Sp. gr. 0.34–0.65, mostly 0.35–0.40. **Sitka Spruce**, *P. sitchensis* (Bong.) Carr.[18]

B Vertical resin ducts normally absent; occasionally present (in certain species) as result of injury and appearing as tangential rows of cysts. Radial resin ducts absent. Ray tracheids present or absent. (For **A**, see p. 110.)

a Tracheids without spiral thickenings. (For **b**, see p. 118.)

a¹ Woods without aromatic scent. (For **b¹**, see p. 116.)

a² Wood parenchyma absent or very sparingly developed and not visible without compound microscope. Heartwood pale, not always clearly defined. Rays rarely biseriate in part; parenchyma cells with thick, distinctly pitted end walls; blind pits numerous. Pits in radial walls of vertical tracheids rarely in horizontal pairs.

a³ Ray tracheids absent or rare. (True) **Fir.**[19]

a⁴ Heartwood white or pale brown in general appearance, with late wood rather purplish. Wood often coarse grained, soft, and weak. Sp. gr. 0.29–0.45, mostly 0.35–0.40. **Eastern or Balsam Fir,** *Abies balsamea* Mill.; **White Firs,** *A. grandis* Lindl. and *A. concolor* Parry; **Silver Fir,** *A. amabilis* (Loud.) Forbes.

b⁴ Heartwood yellowish brown with reddish tinge; rays decidedly reddish. Wood moderately to decidedly heavy and hard. Sp. gr. 0.41–0.58. **Noble Fir,** *A. nobilis* Lindl.; **California Red Fir,** *A. magnifica* Murr.

b³ Ray tracheids always present, usually in single marginal rows and sometimes interspersed. **Hemlock.**[20]

a⁴ Odor disagreeable, though not very pronounced in small dry specimens. Wood harsh and slivery, inclined to split apart at growth rings; brittle. Sp. gr. 0.33–0.52, mostly 0.40–0.45. Contrast between early and late wood pronounced; transition abrupt. Color light buff with reddish brown tinge. **Eastern Hemlock,** *Tsuga canadensis* Carr.

b⁴ Odorless when dry; green wood slightly sour-smelling. Wood of rather uniform texture, not particularly harsh and splintery, straight grained and fairly easy to work. Sp. gr. 0.30–0.57, mostly 0.40–0.50. Contrast between early and late wood not pronounced; transition rather gradual. Color light, sometimes pinkish or reddish brown. Small black checks common. Traumatic resin ducts frequently present. **Western Hemlock,** *T. heterophylla* Sarg.

b² Wood parenchyma always present, visible under hand lens and often collectively to unaided eye, particularly in sapwood; frequently zonate. Heartwood with characteristic color; sapwood white, usually sharply defined. Rays frequently biseriate in part (esp. in *Sequoia*); parenchyma cells with thin, entire or indistinctly pitted end walls; blind pits absent. Pits in radial

walls of vertical tracheids, especially near the ends, often in horizontal pairs or (esp. in *Taxodium*) in rows of 3 or 4.

a³ Heartwood light cherry-red to reddish brown; not waxy in appearance and feel; without characteristic scent or taste. Texture coarse. Traumatic resin ducts occasionally present. Wood variable from light, soft, fine grained, and uniform textured to fairly heavy, hard, coarse grained, and uneven textured. Sp. gr. 0.40–0.52, mostly 0.40–0.45. Ray tracheids occasionally present. **Redwood,** *Sequoia sempervirens* (Lam.) Endl.[21]

b³ Heartwood yellowish, reddish, light to dark brown, or variegated; darker specimens with waxy appearance and feel, and somewhat rancid odor. Texture medium. Traumatic ducts not known to occur. Wood variable from light and soft to moderately hard and heavy. Sp. gr. 0.34–0.55, mostly 0.40–0.50. Ray tracheids absent. **Southern Cypress,** *Taxodium distichum* Rich.[22]

b¹ Woods with aromatic scent. Ray cells with pitted end walls; blind pits absent. **Cedar Group.**[23]

a² Heartwood light clear yellow or slightly brownish, without much distinction between heartwood and sapwood. Late wood inconspicuous. Scent pungent. Taste unpleasantly spicy resinous. Woods varying from light and soft to moderately so. Texture fine, uniform. Sp. gr. 0.40–0.54, average about 0.45.

a³ Color very light. Texture very fine. Scent rather mild, suggesting turnips; unpleasant. Ray tracheids fairly common in low rays. **Alaska Cedar,** *Chamaecyparis nootkatensis* (Lamb.) Sudw.[24]

b³ Color deep yellow, sometimes brownish. Texture moderately fine. Scent very pungent; pleasant in dry wood. Ray tracheids rarely present. **Port Orford Cedar,** *C. Lawsoniana* (A. Murr.) Parl.[25]

b² Heartwood variable from light brown to purple, but never yellow. Late wood distinct; often conspicuous. Scent variable, fragrant, more or less pronounced, but not pungent. Taste not unpleasant.

a³ Wood firm and compact, cutting smoothly across the grain. Moderate contrast between early and late wood; transition gradual. Demarcation between heartwood and sapwood usually distinct.

a⁴ Heartwood pale reddish brown or roseate, uniform; rays brown. Scent pronounced. Taste spicy. Parenchyma strands fairly numerous, zonate, mostly in late wood; usually not visible with lens. Texture fine, uniform. Growth rings regular; late wood fairly conspicuous. Sp. gr. 0.34–0.46, mostly 0.35–0.40. Rays frequently biseriate in part; cells comparatively large; ray tracheids absent or very rare. **Incense Cedar,** *Libocedrus decurrens* Torr.[26]

b⁴ Heartwood purple or deep red, soon becoming dull brown upon exposure to sunlight; often streaked with white; rays deep red or purple. Scent and taste characteristic, but mild; not sweetish or spicy. Parenchyma strands very numerous, deeply colored, mostly in concentric lines visible with lens and often without it. Texture very fine and uniform. Growth rings often very irregular in width and outline, frequently eccentric; summer wood not conspicuous, sometimes doubled or trebled. Wood usually knotty except in very small sizes. Sp. gr. 0.45–0.53, average about 0.49. Rays uniseriate or occasionally with paired cells; cells very small; ray tracheids of sporadic occurrence, irregular. **Eastern Red Cedar,** *Juniperus virginiana* L. and *J. lucayana* Britt.[27]

b³ Wood soft, more or less spongy.

a⁴ Late wood thin, but hard; early wood very soft; transition abrupt. Sp. gr. 0.34–0.42. Heartwood variable, pinkish to dark reddish brown; often streaked; sapwood white, distinct. Wood parenchyma inconspicuous, often zonate in widely separated growth rings. Bordered pits in radial walls usually in pairs near ends of tracheids in early wood. **Western Red Cedar,** *Thuja plicata* Don.[28]

b[4] Late wood rather soft; early wood very soft; transition gradual. Heartwood pale brown or pinkish, never very dark; sapwood white, not very distinct. Resin cells zonate or diffuse. Bordered pits in tracheids rarely paired.

a[5] Heartwood pale brown; often with intermingling of lighter and darker shades. Wood parenchyma rarely visible with lens. Scent very mild. Wood very soft and rather punky; brash. Growth rings mostly narrow. Sp. gr. 0.28–0.37, average about 0.32. **Northern White Cedar,** *Thuja occidentalis* L.[29]

b[5] Heartwood reddish brown or pinkish. Concentric lines of wood parenchyma visible with lens and often without it. Scent more pronounced and wood firmer and less brash than in preceding. Growth rings mostly moderately wide. Sp. gr. 0.30–0.45, mostly 0.30–0.35. **Southern White Cedar,** *Chamaecyparis thyoides* (L.) B.S.P.[30]

b Tracheids with spiral thickenings. Wood parenchyma and ray tracheids wholly absent. (For **a**, see p. 114.)

a[1] Heartwood bright orange to rose-red; sharply defined; odorless. Sapwood thin, pale yellow. Wood uniform and dense. Sp. gr. 0.62–0.70. **Pacific Yew,** *Taxus brevifolia* Nutt.[31]

b[1] Heartwood bright clear yellow, without pronounced demarcation from sapwood; scent mild, unpleasant. Sp. gr. 0.44–0.60, mostly around 0.50. **California Nutmeg,** *Tumion californicum* (Torr.) Greene or *Torreya californica* Torr.; **Stinking Cedar,** *Tumion taxifolium* (Arn.) Greene or *Torreya taxifolia* Arn.[32]

II. Dicotyledons or Hardwoods

Vessels present; variable in size from large and conspicuous to minute. Other vertical elements of few to several kinds. Wood parenchyma present, sometimes abundant and conspicuous. Vertical intercellular canals (gum ducts) develop in a few species as a result of injury. Rays variable from minute to very large.

Growth layers indicated by various structural differences; distinct to indistinct. Scent and taste sometimes characteristic.

A Ring-porous Woods. Pores of one part of a growth ring in distinct contrast in size and number (or both) to those of the other part. (For **B**, see p. 125.)

a Late wood with *radial* lines or patches (frequently branched or fan-like) composed of small pores and parenchyma which usually are of lighter color than the background; also with fine concentric lines of metatracheal parenchyma, distinct to indistinct. Vessels without spiral thickenings; large members with rounded pits and simple perforations; small members with tendency to be scalariformly pitted and perforated; pits to ray cells either bordered or simple. Vasicentric tracheids present. Rays more or less heterogeneous; pits to vessels rather large, irregular, often vertically elongated. Ground mass composed of fiber-tracheids.

a¹ Rays all very fine; indistinct without lens on cross and tangential sections. Density medium; sp. gr. 0.45–0.59. Rays uniseriate or occasionally biseriate in part; mostly 5–15 cells high.

a² Pores in early wood few, comparatively small, nearly circular, open, and rather widely separated in a single row. Heartwood light brown to roseate; odorless and tasteless when dry. **Golden Chinquapin,** *Castanopsis chrysophylla* (Hooker) A. DC.[33]

b² Pores in early wood very numerous, large, mostly oval or elliptical, often closed with tyloses, and crowded in a broad zone. Heartwood brown; odor mild but distinct; taste somewhat astringent because of tannin. **Chestnut,** *Castanea dentata* (Marsh.) Borkh.[34]

b¹ Rays of two distinct sizes, the large ones conspicuous, the small ones very fine and mostly invisible without lens. Wood hard and heavy; sp. gr. 0.65–0.90. Odor of fresh wood characteristic. **Oak.**[35]

a² Pores in late wood individually distinct under lens and few enough to be readily counted; arranged mostly in fairly definite radial rows, except in narrow rings. Pores in early wood usually crowded in a

broad zone and becoming gradually smaller outward (occasional exceptions). All pores usually open; sometimes partially or wholly closed with tyloses. Large rays appear on tangential surface as rather short lines (rarely exceeding 1 inch), more or less interrupted by wood fibers. Heartwood typically pale reddish brown. Pores in late wood thick walled, sub-circular. **Red Oak Group,** *e.g., Quercus borealis maxima* (Marsh.) Ashe.[36]

b² Pores in late wood rarely individually distinct under lens and not few enough to be readily counted; arranged in fan-like patches often joined tangentially in outer portion. Pores in early wood in few (1–3) rows, usually not crowded; transition to those of late wood abrupt, except sometimes in very wide rings; usually closed with tyloses in heartwood. Large rays appear on tangential surface as narrow, straight lines of variable lengths up to 5 inches. Heartwood light to rather dark brown; rarely pinkish. Pores in late wood thin walled, angular in outline. **White Oak Group,** *e.g., Quercus alba* L.[37] (For Evergreen and Live Oaks, which are diffuse-porous, see p. 126.)

b Late wood without distinct radial lines or patches of pores and parenchyma. Vessels with or without spiral thickenings; pitting not scalariform; perforations exclusively simple (except in small vessels of *Sassafras*).

a¹ Pores in late wood numerous. Small pores rather thin walled; pit canals not coalescent. Ground mass composed of libriform fibers. (For **b**¹, see p. 124.)

a² Pores in late wood very small and numerous, and arranged in conspicuous tangential or concentric *bands* or *festoons*, often broken, esp. near early wood; usually giving rise to wavy or zigzag pattern on tangential surface. Wood parenchyma paratracheal and terminal; not distinct with lens. Sp. gr. 0.60–0.85. Smaller vessels with spiral thickenings.

a³ Pores in early wood in a single row, except sometimes in wide growth rings. Woods without distinctive odor or taste. Rays homogeneous; mostly less than 6 cells wide and not distinctly two-sized. **Elm.**[38]

a[4] Pores in early wood rather large and distinct, mostly open, usually forming a fairly continuous row. Different parts of the same growth ring often widely variable in thickness. Wood coarse textured, tough and difficult to split, saws woolly. Heartwood light brown to grayish. Sp. gr. 0.60–0.75. **Soft Elm**, *Ulmus americana* L.

b[4] Pores in early wood small to minute, mostly closed with tyloses in heartwood; larger pores few and rather widely separated in a band of small ones. Different parts of the same growth ring of fairly uniform thickness. Wood medium textured, fairly easy to split, saws rather smoothly. Heartwood light brown. Sp. gr. 0.70–0.85. **Rock Elm**, *U. racemosa* Thom.

b[3] Pores in early wood in few to several rows, except sometimes in narrow growth rings.

a[4] Heartwood dark brown; with more or less distinctive odor of licorice; distinct from sapwood. Rays often obscure without lens on cross section. Texture coarse. Sp. gr. 0.65–0.80. Rays homogeneous; not so large as in preceding (usually less than 6 cells wide) and not distinctly two-sized. **Gray Elm**, *Ulmus fulva* Michx.

b[4] Heartwood gray or yellowish gray; odorless; scarcely distinct from sapwood. Rays very distinct on cross section. Texture very coarse. Sp. gr. 0.65–0.80. Rays heterogeneous; of two distinct sizes, uniseriate and multiseriate (mostly 6–10 cells). **Hackberry**, *Celtis occidentalis* L. and *C. laevigata* Willd.[39]

b[2] Pores in late wood variable in size from fairly large to minute, occurring in *clusters*. Wood parenchyma paratracheal and often confluent; usually distinct.

a[3] Woods hard and heavy. Heartwood distinctively colored; odorless (except in *Prosopis*). Rays distinct; commonly more than 3, sometimes up to 10, cells wide.

a⁴ Tyloses present, light colored. Gum deposits absent or only occasional. Sapwood thin to very thin. Small vessels with spiral thickenings. Rays more or less heterogeneous.

a⁵ Late wood not horn-like. Heartwood orange-yellow to yellow-brown, not uniform; becoming russet-brown upon exposure; tyloses not always abundant. Rays distinct on cross section, conspicuous on radial surface. Sp. gr. 0.55–0.65. Bordered pits not vestured. **Mulberry,** *Morus rubra* L.[40]

b⁵ Late wood horn-like. Heartwood mostly light yellow when fresh; tyloses abundant. Rays visible on cross section, inconspicuous on radial surface.

a⁶ Heartwood golden yellow when fresh, becoming dark orange-brown upon exposure; frequently with rather distinct reddish longitudinal streaks; highly lustrous. Wood usually cross grained and knotty; small pin knots due to thorns common; worm holes absent in heartwood. Bordered pits not vestured. **Osage Orange,** *Toxylon pomiferum* Raf. or *Maclura aurantiaca* Nutt.[41]

b⁶ Heartwood golden yellow to brown, often greenish brown in young trees; usually uniform in same specimen; not striped with red. Wood fairly straight grained, without pin knots due to thorns; large worm holes very common. Bordered pits vestured. **(Black** or **Yellow) Locust,** *Robinia pseudoacacia* L.[42]

b⁴ Tyloses absent. Gum deposits common, in some cases abundant. Small vessels with or without spiral thickenings. Bordered pits vestured. Rays mostly homogeneous.

a⁵ Wood parenchyma usually abundant and conspicuous in all parts of growth ring, paratracheal, confluent, and terminal. Pores

very irregular in size, number, and arrangement; with distinct tendency to become diffuse. Sapwood thin, greenish yellow. Heartwood purplish brown, flecked with abundant gum deposits in vessels; sweet-scented when fresh. Sp. gr. about 0.77. Vessels without spiral thickenings. **Mesquite,** *Prosopis juliflora* (Swartz) DC.[43]

b^5 Wood parenchyma mostly about pore clusters in late wood, sometimes confluent, esp. in wide rings. Pores distinctly of two sizes, those in outer late wood all very small and clustered; arrangement characteristic. Heartwood without distinctive scent. Gum deposits usually few, inconspicuous. Sp. gr. 0.67–0.70. Small vessels with spiral thickenings.

a^6 Individual pores in late-wood clusters distinct under lens. Sapwood thin, greenish yellow. Heartwood light cherry-red to reddish brown. Texture very coarse. No small pin knots due to thorns. **(Kentucky) Coffee-tree,** *Gymnocladus dioicus* (L.) Koch.[44]

b^6 Individual pores in late-wood clusters minute, usually not distinct under lens. Sapwood thick, yellowish. Heartwood pale reddish brown or bronze. Texture moderately coarse. Small pin knots due to thorns common. **Honey Locust,** *Gleditsia triacanthos* L.[45]

b^3 Woods light and soft. Heartwood not distinctively colored, mostly pale brown; with characteristic odor. Tyloses present. Gum deposits absent. Rays mostly 2, occasionally 3, cells wide; heterogeneous.

a^4 Rays distinct on cross section without lens. Heartwood aromatically scented. Texture coarse. Sp. gr. about 0.50. Members of small vessels with scalariform perforation plates and without spiral thickenings. Vessel-parenchyma pit-pairs large,

simple to half-bordered. Oil cells present in some rays and wood parenchyma strands. **Sassafras**, *Sassafras variifolium* (Salisb.) Ktze.[46]

b[4] Rays indistinct on cross section without lens. Heartwood with mild odor suggesting kerosene. Texture medium. Sp. gr. 0.40–0.45. Members of small vessels with simple perforations and spiral thickenings. Vessel-parenchyma pit-pairs smaller, half-bordered. Oil cells absent. **Catalpa**, *Catalpa speciosa* Ward.[47]

b[1] Pores in late wood few, solitary or in small multiples. Woods without distinctive odor or taste. Small pores thick walled; pit canals often coalescent. All vessels without spiral thickenings. Ground mass usually composed of fiber-tracheids; libriform fibers also present in certain cases.

a[2] Wood parenchyma in late wood paratracheal, often aliform and in some species confluent; also terminal. Pores in late wood all much smaller than those of early wood; the latter usually in a rather broad zone, 3–10 (rarely 1 or 2) pores wide. Terminal parenchyma cells with radial walls very irregularly thickened. Rays homogeneous or nearly so; pits to vessels minute. **Ash.**[48]

a[3] Paratracheal parenchyma in late wood not distinctly aliform nor confluent into long lines. Heartwood brown to dark brown. Sapwood usually thin. Sp. gr. about 0.47. **Black** or **Brown Ash**, *Fraxinus nigra* Marsh.

b[3] Paratracheal parenchyma in late wood often long aliform, becoming confluent, esp. in wider rings, into irregular tangential to fairly regular concentric lines. Heartwood grayish brown, sometimes with distinct reddish tinge, esp. in late wood. Sapwood usually thick. Sp. gr. 0.63–0.72. **White Ash**, *e.g.*, *F. americana* L. and *F. pennsylvanica lanceolata* (Bork.) Sarg.

b[2] Wood parenchyma in late wood in numerous fine metatracheal lines; also terminal. Pores in late wood sometimes approaching in size those of the early wood; the latter comparatively few and irregularly arranged. Terminal parenchyma cells with

radial walls rather uniformly thickened. Rays more or less heterogeneous.

a^3 All elements storied; ripple marks visible, wavy, 60–80 per inch of length. Lines of wood parenchyma scarcely distinct with lens; finer than the rays. Heartwood reddish brown to black, often streaked; tyloses absent. Sapwood white or gray. Sp. gr. about 0.79. Rays fairly uniform in height; 1 or 2 (occasionally 3) cells wide; pits to vessels very small, crowded. All pores thick walled; those in multiples thicker walled, esp. at the corners. Metatracheal parenchyma lines uniseriate; pits on radial walls clustered; crystals numerous, small. **Persimmon,** *Diospyros virginiana* L.[49]

b^3 Elements not storied. Lines of wood parenchyma as distinct as the rays; faintly visible without lens. Heartwood brown to reddish brown, sometimes with darker streaks; tyloses present. Sapwood white, often with tinge of pink. Sp. gr. 0.70–0.85. Rays very irregular in height and arrangement; 1–5 cells wide; pits to vessels small, numerous. When solitary, large pores uniformly thin walled; when in multiples, with adjacent walls much thickened, esp. at the corners. Metatracheal parenchyma lines 1–3 cells wide; pits on radial walls clustered; crystals few, large. **Hickory,** *Hicoria* (*Carya*) spp.[50]

B Diffuse-porous Woods. Pores of fairly uniform or only gradually changing size and distribution throughout a growth ring. Ground mass of wood composed of fiber-tracheids (except in *Umbellularia*, *Salix*, and *Populus*).

a Pores variable in size, the larger ones readily visible without lens; not very numerous, not crowded. Growth rings distinct. Vessel lines conspicuous. Metatracheal parenchyma lines present in late wood.

a^1 All rays fine and inconspicuous. Pores solitary or in small multiples, rather uniformly distributed, with tendency to diagonal alinement; tyloses present. Paratracheal parenchyma not distinct with lens. Vessels without spiral thickenings; perforations exclusively simple; pits to parenchyma simple. Rays homogeneous to rather

distinctly heterogeneous; 1–4 cells wide and few to 30 (sometimes up to 70) cells high; pits to vessels oval, radially elongated. Growth rings terminated by narrow, sharply defined band of flattened, thicker-walled fibers and a uniseriate layer of parenchyma. **Walnut.**[51]

a² Heartwood dark or chocolate-brown, often with purplish tinge; sometimes variegated. Sapwood usually thick. Wood rather hard and heavy. Sp. gr. 0.60–0.70. Crystals common in parenchyma strands. Ray cells round in tangential section. Pores and fibers comparatively thick walled. **Black Walnut,** *Juglans nigra* L.

b² Heartwood pale chestnut brown, with darker zones. Sapwood thin. Wood light and soft. Sp. gr. 0.35–0.45. Crystals absent. Ray cells flattened laterally. Pores and fibers thin walled. **Butternut,** *J. cinerea* L.

—

b¹ Some of the rays coarse and conspicuous. Pores solitary in radial lines or bands between the broad rays; tyloses usually absent. Paratracheal parenchyma abundant, distinct with lens. Vessels without spiral thickenings; small members sometimes with scalariform perforation plates; pits to parenchyma bordered or simple. Rays of two distinct sizes, namely, uniseriate and low, multiseriate and high; pits to vessels irregular, often vertically elongated. Flattened fibers at termination of growth ring not forming a sharply defined layer; no line of terminal parenchyma. **Live Oak,** *e.g., Quercus virginiana* Mill.

b Pores small to minute, often not individually distinct without lens; mostly well distributed throughout growth rings; sometimes few and scattered but more often crowded. Vessel lines not conspicuous. Metatracheal parenchyma lines present or absent.

a¹ Pores and pore groups in radial lines, not crowded laterally. Metatracheal parenchyma present.

a² Metatracheal parenchyma lines visible under lens on moist cross section. Pores from medium-sized and visible to unaided eye in early wood to minute and scarcely distinct with lens in outer late wood. Rays crowded, less than two pore-widths apart. Wood dense. Vessels with spiral thickenings; perforations simple or with tendency to multiple in smallest vessels; pits

to rays rather large to very small, simple; intervascular pitting alternate. Fiber-tracheids without spiral thickenings. Rays 1–3 cells wide.

a³ Rays all invisible on cross section without lens; no aggregate rays present. Pores in outer late wood minute and in clusters that appear to unaided eye as white dots. Growth rings not characteristically sinuous. Heartwood light brown. Sapwood lighter colored, somewhat roseate. Sp. gr. about 0.83. Rays heterogeneous in part. **Hop Hornbeam,** *Ostrya virginiana* (Mill.) Koch.[52]

b³ Broad, aggregate rays present and conspicuous; usually in groups. Pores in outer late wood sometimes as in preceding. Growth rings characteristically sinuous. Heartwood yellowish white; usually not distinguishable from sapwood. Sp. gr. about 0.83. Rays homogeneous. **Blue Beech,** *Carpinus caroliniana* Walt.[53]

b² Metatracheal parenchyma lines not visible with lens. Pores all small, not visible to the unaided eye; arranged in long, fairly regular, single to triple radial rows; not clustered. Rays coarse, but not always distinct because of lack of color contrast with background; spaced several to many pore-widths apart. Wood moderately dense. Sp. gr. 0.51–0.66, av. about 0.58. Heartwood chalky white or somewhat bluish; usually not distinguishable from sapwood. Vessels with spiral thickenings; perforation plates scalariform, with many bars; pits to rays small, uniform, bordered; intervascular pitting mostly opposite. Fiber-tracheids with spiral thickenings. Rays of two distinct sizes, namely, uniseriate and multiseriate (3–5 cells wide and up to 60 cells high); decidedly heterogeneous. Wood parenchyma sparingly developed, in short uniseriate lines or diffuse. **Holly,** *Ilex opaca* Ait.[54]

b¹ Pores not in distinct radial lines, although often in short radial groups or multiples. Metatracheal parenchyma sometimes present, but not distinct with lens.

a² Pores solitary or in small multiples; rather few to fairly numerous, but not crowded. (For **b²**, see p. 130.)

a[3] Rays not distinct on cross section without lens; narrower than the pores.

a[4] Parenchyma encircling the pores and pore-multiples, distinct under lens. Heartwood yellowish brown; spicily scented. Growth rings distinct because of narrow but dense late wood; no line of terminal parenchyma. Vessels without spiral thickenings; perforations simple; pits comparatively large, those to ray cells mostly simple. Rays heterogeneous; 1–3 (mostly 2) cells wide and few to 25 (mostly under 15) cells high, the cells rounded (tang. sec.). Large oil cells present in rays and some of the wood parenchyma strands. Wood parenchyma vasicentric. Wood fibers with simple pits. **Oregon Myrtle**, *Umbellularia californica* (H. & A.) Nutt.[55]

b[4] Parenchyma not encircling the pores, barely visible with lens. Heartwood not spicily scented. Growth rings usually distinct, partly because of fine lines of terminal parenchyma. Vessels without spiral thickenings; perforation plates scalariform, with many fine bars; pits all bordered, very numerous, exceedingly small. Rays homogeneous or nearly so; 1–5 cells wide, the cells often flattened laterally. Wood parenchyma in single terminal layer and sparingly metatracheal and diffuse. Oil cells entirely absent. Wood fibers with bordered pits.
Birch.[56]

a[5] Heartwood brown tinged with red, sometimes deeply reddish. Pith flecks rare. Sp. gr. 0.60–0.80, mostly 0.65–0.75. *Betula lenta* L. and *B. lutea* Michx. f.

b[5] Heartwood pale brown. Pith flecks common. Sp. gr. 0.46–0.64. *Betula papyrifera* Marsh. and *B. populifolia* Marsh.

b[3] Rays distinct on cross section without lens; often as wide as or wider than the pores. Growth rings not terminated by line of wood parenchyma. Ray cells nearly circular in tangential section, hence rays of same cell-width usually appreciably wider than in

Betula; also all vessel pits larger, and much less numerous, than in that genus.

a⁴ Wood parenchyma not in tangential lines. Color variable from very light to brown or reddish brown. Density variable. Vessels with spiral thickenings; perforations simple; intervascular pitting alternate. Rays homogeneous or nearly so; not always distinctly two-sized. **Maple.**[57]

a⁵ Larger rays wider than the pores; conspicuous on radial surface. Growth rings very distinct, being terminated by a thin layer of deeper color. Curly and bird's-eye grain fairly common. Pith flecks rare. Av. sp. gr. about 0.69. Larger rays 5–7 cells wide; uniseriate rays very numerous. **Hard Maple,** *Acer saccharum* Marsh. and *A. nigrum* Michx. f.

b⁵ Larger rays not as wide as the pores; distinct to inconspicuous on radial surface. Growth rings not always distinct. Bird's-eye grain absent.

a⁶ Heartwood deeply and richly colored. Wavy grain fairly common. Pith flecks rare. Av. sp. gr. about 0.49. Rays not distinctly two-sized; mostly 3–5 cells wide; uniseriate rays few. **Bigleaf Maple.** *A. macrophyllum* Pursh.

b⁶ Heartwood light colored. Rays distinctly two-sized; larger ones 3–5 cells wide; uniseriate rays fairly numerous.

a⁷ Heartwood pale brown, often with greenish hue. Pith flecks very common, sometimes abundant. Rays darker than background on radial surface. Av. sp. gr. about 0.62. **Soft Maple,** *A. rubrum* L. and *A. saccharinum* L.

b⁷ Heartwood yellow or yellowish brown, often with pink or red streaks due to

fungus. Pores smaller and more numerous than in preceding. Pith flecks rare. Rays of same color as background on radial surface. Av. sp. gr. about 0.43. **Boxelder,** *A. Negundo* L. or *Negundo aceroides* Moench.

b[4] Wood parenchyma in fine, irregular metatracheal lines, faintly visible with lens on moist cross section. Heartwood roseate to reddish brown, sometimes with greenish hue. Wood dense. Vessels without spiral thickenings; perforation plates scalariform, with many narrow bars; intervascular pitting often scalariform. Rays decidedly heterogeneous; distinctly two-sized. **Dogwood.**[58]

a[5] Larger rays considerably wider than the pores; very conspicuous on radial surface. Sp. gr. 0.76–0.89, av. about 0.82. Rays 1–7 cells wide and up to 80 cells high. **(Flowering) Dogwood,** *Cornus florida* L.

b[5] Larger rays of approximately the same width as the pores; not very conspicuous on radial surface. Sp. gr. about 0.75. Rays 1–4 cells wide and up to 40 cells high. **Pacific Dogwood,** *C. Nuttallii* Aud.

b[2] Pores very numerous, usually crowded together.

a[3] Largest rays wider than the pores; very distinct on radial surface. (For **b**[3], see p. 132.)

a[4] Heartwood rich reddish brown, with golden luster; vessels with gum plugs, but without tyloses. Rays indistinct on tangential surface; appear lighter than background on the radial; not distinctly two-sized; largest not much wider than the pores. Growth layer boundaries usually appear lighter colored than background on tangential surface. Vertical gum ducts, gummosis type, frequently present. Wood parenchyma not visible with lens. Sp. gr. 0.50–0.71, av. about 0.58. Vessels with spiral thickenings; perforations exclusively simple; intervascular pitting alternate. Rays 1–7, mostly 3–5,

cells wide and few to 100 cells high; somewhat heterogeneous. Wood parenchyma very sparingly developed as single strands in contact with pores or diffuse. **Cherry,** *Prunus serotina* Ehrh.[59]

b^4 Heartwood light brown to reddish brown; not highly lustrous; vessels with tyloses, but without gum plugs. Rays very distinct on all sections; appear darker than background on radial surface; largest much wider than the pores. Gum ducts absent. Vessels without spiral thickenings; intervascular pitting frequently opposite or scalariform.

a^5 Rays nearly all broad, numerous, fairly uniformly spaced; conspicuous on all sections. Wood parenchyma not visible with lens. Late wood thin, of lighter color than the early wood. Roe or ribbon grain common on radially cut lumber. Heartwood light brown to pinkish. Sp. gr. 0.47–0.57. Many of the vessel members scalariformly perforated; bars thin, few to numerous. Rays homogeneous; occasionally low and uniseriate, but mostly 5–8 cells wide and 100–300 cells high. Wood parenchyma sparingly developed, mostly in short uniseriate lines or diffuse. **Sycamore,** *Platanus occidentalis* L.[60]

b^5 Rays of two sizes, the larger ones rather few and irregularly spaced; less conspicuous than in *Platanus*. Wood parenchyma in fine, irregular lines, sometimes visible with lens. Late wood rather thick, of darker color than the early wood. Roe or ribbon grain not characteristic. Heartwood pale to dark or reddish brown; mostly uniform. Sp. gr. 0.65–0.80, av. about 0.69. Members of smaller vessels sometimes scalariformly perforated; bars few, rather thin. Rays heterogeneous in part; widely variable in size, many uniseriate and 1–15 cells high, others 2–8 cells wide and 15–40 cells high, the largest up to 25 cells wide and 100–200 cells high; cells considerably smaller than in *Platanus*. Wood parenchyma

strands in irregular uniseriate rows. **Beech,** *Fagus grandifolia* Ehrh.[61]

b³ Rays narrower than the pores (except aggregate rays of *Alnus*); distinct to indistinct or invisible on cross section.

a⁴ Rays either distinct to unaided eye on cross section or some of them high and conspicuous on radial surface; mostly two to several pore-widths apart.

a⁵ Growth rings terminated by distinct light-colored line or band of parenchyma. Ripple marks absent. Rays low and inconspicuous on radial surface. Heartwood clearly demarcated. Saws smoothly. Vessels with tyloses; spiral thickenings absent or indistinct; perforation plates mostly scalariform (simple perforations in *Magnolia acuminata*); intervascular pitting opposite or scalariform; vessel-ray pitting often unilaterally compound. Rays of fairly uniform size for each species; nearly homogeneous to distinctly heterogeneous; cell walls thick, abundantly and irregularly pitted; cells not much flattened laterally; crystals absent. Wood parenchyma aggregated in terminal layer 1–5 cells thick; radial walls heavily and irregularly thickened, the pits clustered: no metatracheal lines.

a⁶ Pores of uniform size and distribution throughout growth ring. Heartwood variable in color from bright greenish yellow or olive to purplish; light-colored wood becomes dark brown upon exposure; curly grain and mottle not uncommon. Sapwood thick to very thick; sharply demarcated. Sp. gr. 0.35–0.48, av. about 0.42. Vessels without spiral thickenings; pits in tangential walls mostly elliptical or rectangular and arranged in definite horizontal rows; perforation plates scalariform, with few to numerous, narrow, rather widely spaced bars. Rays mostly 3-seriate, few to 60 (mostly 20–40) cells high; heterogeneous. Terminal paren-

chyma 1 or 2 cells wide. **Yellow Poplar,** *Liriodendron tulipifera* L.[62]

b[6] Pores fewer and smaller in late wood; less numerous than in *Liriodendron.* Vessels with fine, distinct to indistinct, spiral thickenings; pits in tangential walls mostly linear and scalariformly arranged.

a[7] Heartwood yellow or olive; often closely resembling *Liriodendron.* Late wood narrow. Sp. gr. 0.42–0.54, av. about 0.47. Vessels nearly always with simple perforations; spiral thickenings indistinct. Rays 1–4 (mostly 2) cells wide and few to 25 (mostly 10–15) cells high; fairly homogeneous. Terminal parenchyma 1 or 2 cells wide. **Cucumber,** *Magnolia acuminata* L.[63]

b[7] Heartwood light brown, sometimes with greenish hue. Late wood broad. Pores less numerous than in preceding. Sp. gr. about 0.50. Vessel perforation plates scalariform, mostly with several widely spaced bars. Rays heterogeneous. Terminal parenchyma 2–6 cells wide.

a[8] Spiral thickenings in vessels distinct. Rays mostly biseriate, 15–60 (mostly 30–35) cells high. *M. grandiflora* L.

b[8] Spiral thickenings in vessels indistinct. Rays 1–4 cells wide, 10–100 (mostly 20–40) cells high. *M. virginiana* L.

b[5] Line of terminal parenchyma not visible without lens and not distinct with it. Ripple marks present, faintly visible, 55–60 per inch of length; larger rays not storied. Some of the rays high and conspicuous on radial surface. Heartwood creamy white to brown, not always clearly demarcated. Saws rather woolly. Sp. gr. 0.38–0.52, mostly 0.40–0.45. Vessels with spiral thickenings; tyloses absent; perforations exclusively sim-

ple; intervascular pitting alternate; vessel-ray pitting not unilaterally compound. Rays of two general sizes, namely, uniseriate and 10–15 cells high, and multiseriate (3–5 cells) and 50–100 cells high; homogeneous or occasionally distinctly heterogeneous; cell walls thin, fairly uniform; cells much flattened laterally; crystals numerous. Wood parenchyma metatracheal in numerous uniseriate lines, and in single terminal row; walls thin, uniform. **Basswood**, *Tilia glabra* Vent. and other species.[64]

b[4] Rays (except aggregate rays in *Alnus*) indistinct or invisible to unaided eye on cross section, and low and inconspicuous on radial surface; mostly only 1–2 pore-widths apart.

a[5] Rays distinct with lens on cross section.

a[6] Aggregate rays present, although often widely separated. Wood straight grained, rather light but firm; sp. gr. 0.43–0.48. Heartwood pale brown or bronze-colored, not readily distinguishable from sapwood; surface of freshly felled timber often stains greenish brown; luster low. Growth rings fairly distinct. Pores very numerous, of fairly uniform size and distribution. Vessels without spiral thickenings; perforation plates scalariform, with many narrow, rather closely spaced bars; intervascular pitting opposite; tyloses absent; pores angular. Non-aggregated rays uniseriate, rarely biseriate in part; homogeneous. Aggregate rays 15–25 cells wide, very irregular, as seen in tangential section. Wood parenchyma scarce, diffuse. Fiber-tracheids variable in cross section, but usually not distinctly squarish; terminal 2–4 rows much flattened; pits irregularly distributed, small, the border circular, the aperture slit-like and slightly extended. **Red Alder**, *Alnus rubra* Bong.[65]

b[6] No aggregate rays present. Woods with irregular or interlocked grain.

a[7] Heartwood dark colored, dull brown to reddish brown; sharply demarcated.

a[8] Growth rings distinct owing to greater abundance of pores in early wood. Heartwood reddish brown, fairly uniform. Sapwood rather thin, yellowish when fresh, later becoming light pinkish brown. Gum ducts absent. Sp. gr. about 0.75. Vessels wholly without spiral thickenings; perforations simple; pits in tangential walls rounded, alternate; tyloses absent; pores rounded. Rays 1–4 cells wide, few to 25 cells high; mostly homogeneous. Wood parenchyma in short uniseriate lines and diffuse. Fiber-tracheids rounded in cross section; pits numerous, large, the border circular, the aperture lenticular and included. **Apple,** *Pyrus Malus* L.[66]

b[8] Growth rings usually indistinct, the pores being uniform in size and distribution. Grain more interlocked than in *Pyrus.* Heartwood variable from light to dark brown, often with irregular dark streaks independent of the growth layers. Sapwood thick, pale brown, sometimes with dark streaks. Vertical gum ducts sometimes present in tangential rows as result of injury. Sp. gr. 0.50–0.60. Vessels with spiral thickenings limited to the constricted extensions of the members; perforation plates scalariform, with many narrow and rather closely spaced bars; pits in tangential walls opposite or scalariform; tyloses present; pores angular. Rays 1–3 cells wide, few to 40 cells high; heterogeneous. Wood parenchyma scarce, diffuse. Fiber tracheids dis-

tinctly squarish in cross section; pits rather large and numerous, the border circular, the aperture slit-like and extended. **Red Gum** or **Gumwood,** *Liquidambar styraciflua* L.[67]

b[7] Heartwood light colored, pale brown, grayish, or yellowish; fairly uniform; not sharply demarcated. Grain interlocked. Growth rings usually indistinct. Pores variable in size and abundance in different species. Gum ducts absent. Vessels without spiral thickenings; tyloses absent; perforation plates scalariform or reticulate-scalariform, with many narrow, rather closely spaced bars; intervascular pitting opposite or scalariform; tyloses absent; pores angular. Rays 1–4 cells wide, few to 30 cells high; decidedly heterogeneous. Wood parenchyma scarce, diffuse or in short metatracheal rows. Fiber-tracheids not distinctly squarish in cross section; pits not very numerous, rather small, the border circular, the aperture slit-like and extended. **Black Gum** and **Tupelo.**[68]

a[8] Wood usually dense, tough, and strong. Pores minute; not crowded. Sp. gr. 0.56–0.75, av. about 0.64. Rays rarely over 2 cells wide. **Black Gum,** *Nyssa sylvatica* Marsh.

b[8] Wood rather light, but firm, tough but not very strong. Pores small, crowded. Sp. gr. 0.40–0.56, av. about 0.50. Rays often over 2 cells wide. **Tupelo,** *N. aquatica* L. and *N. biflora* Walt.

b[5] Rays indistinct or invisible with lens on cross section. Vessels with simple perforations; intervascular pitting alternate; tyloses present. Rays uniseriate, few to 20 cells high, the cells flattened laterally. Growth rings terminated by 1 or 2 rows of wood parenchyma.

a6 Pores minute, invisible without lens; uniform in size and usually also in distribution; not arranged in tangential or diagonal bands. Heartwood pale yellow, not readily distinguishable from sapwood. Luster silky. Sp. gr. 0.42–0.50. Vessels with spiral thickenings; pits to ray cells of variable forms, simple to bordered. Rays heterogeneous; the squarish or irregular marginal cells, when in contact with vessels, with numerous oval pits, often closely spaced in horizontal or diagonal rows; interior ray cells without pits to vessels. Fibers thin walled; pits mostly with very small circular border and slit-like extended aperture. **Buckeye.**[69]

a7 All elements storied; ripple marks distinct, fairly regular, 65–70 per inch of length. **Yellow Buckeye,** *Aesculus octandra* Marsh.

b7 Elements not regularly storied; ripple marks absent or local. **Ohio Buckeye,** *A. glabra* Willd.; **California Buckeye,** *A. californica* Nutt.

b6 Pores small, but usually visible without lens, except in Aspen; larger and more numerous in early wood; frequently with distinct tangential or diagonal arrangement. Vessels without spiral thickenings; pits to rays large, sub-circular. Both interior and marginal cells of the rays pitted when in contact with vessels. Fibers thin walled; pits rather few, minute, rounded, simple.

a7 Heartwood dull reddish brown, often streaked. Texture coarse. Feel rather harsh. Wood saws rather smoothly. Sp. gr. 0.41–0.47. Rays heterogeneous. **Willow,** *Salix nigra* Marsh.[70]

b7 Heartwood pale brown, grayish, or nearly colorless. Wood saws woolly. Rays homogeneous. **Poplar.**[71]

a[8] Texture coarse. Feel rather harsh. Luster low. Sp. gr. 0.32–0.48. **Cottonwood,** *Populus deltoides* Marsh., *P. heterophylla* L., *P. trichocarpa* Hook.[72]

b[8] Texture fine. Pores usually invisible without lens. Feel soft. Luster silky. Sp. gr. 0.36–0.51, mostly 0.40–0.45. **Aspen,** *P. tremuloides* Michx. and *P. grandidentata* Michx.[73]

NOTES AND REFERENCES

1. Pines. There are 35 species of *Pinus* native to the United States. Although 28 of them are of more or less commercial importance, the bulk of the lumber is obtained from about eight species — two northern, three southern, and three western. On the basis of their ray structure the woods are readily separable into four groups as indicated in the key, but specific determinations within the groups are often uncertain or impossible.

HALL, WILLIAM L., AND HU MAXWELL: *Uses of the commercial woods of the United States. II. Pines.* Bul. 99, U. S. Forest Service, Washington, D. C., 1911, pp. 96.

ROL, R.: Note sur un essai de classification du genre *Pinus* d'aprés des caractéres tirés de l'anatomie du bois. *Soixante-cinquième Congrès des Sociétés Savantes,* 1932, pp. 333–341.

2. White Pine Group. In addition to the three species enumerated, there are three of little or no commercial importance in the western mountainous regions, namely, *Pinus flexilis* James (Limber Pine), *P. albicaulis* Engelm. (Whitebark Pine), and *P. strobiformis* Engelm. (Mexican White Pine). Among the exotic woods of similar anatomy are *P. cembra* L., of the Carpathian Alps and northeastern Russia and Siberia; *P. koraiensis* S. & Z., of Corea or Chosen; *P. Armandi* Franch., of China and Formosa; *P. parviflora* S. & Z., in the mountains of Hondo, Japan; and *P. excelsa* Wallich, of the Himalaya Mountains.

ANONYMOUS: *The white pines.* Technical note No. 215, U. S. Forest Products Laboratory, Madison, Wisconsin, 1925, pp. 4.

ROCKWELL, F. I.: The white pines of Montana and Idaho; their distribution, quality, and uses. *Forestry Quarterly* (Ithaca, New York) 9: 2: 219–231, June 1911.

3. Northern White Pine. It is estimated that the total original stand of this timber was approximately 900 billion board feet, equally divided between the U. S. and Canada. It was formerly extensively used for innumerable purposes of general construction, carpentry, planing-mill and factory products. High-grade lumber is now largely restricted to pattern-making, sash and door manufacture, and other exacting uses, and is replaced for many

purposes by Idaho White Pine and Sugar Pine. Much of the lumber now being cut is from young or "second-growth" trees, and is principally used for boxes, pail stock, and matches. The species is planted for ornamental and forestry purposes. Alternative trade names are Northern Pine, White Pine, Soft White Pine, Cork Pine, with or without the name of state or locality of origin.

DETWILER, SAMUEL B.: The white pine. *American Forestry* (Washington, D. C.) 22: 271: 387–394, July 1916.

SPALDING, V. M., AND B. E. FERNOW: *The white pine.* Bul. 22, U. S. Div. Forestry, Washington, D. C., 1899, pp. 185.

4. Western White Pine. This timber tree is at its best in northern Idaho and adjacent regions of Montana and British Columbia. The lumber is usually known in the eastern market as Idaho White Pine. It is used for the identical purposes as *Pinus strobus,* from which species it ordinarily is not distinguishable.

ANONYMOUS: *Idaho white pine; its properties, uses, and grades.* Pub. by Western Pine Manufacturers Assn., Portland, Oregon, 1931, pp. 64.

HANZLIK, E. J.: Western white and sugar pine. *Four L Lumber News* (Portland, Oregon) 9: 8: 36–37, April 1927.

5. Sugar Pine. This, the largest tree of the White Pine group, is limited in distribution to California and Oregon, and commercial stands are confined practically to the west side of the Sierra Nevadas and portions of the Coast Range. The lumber is used for much the same purposes as *P. strobus* and *P. monticola* and is obtainable in much larger sizes.

COOPER, ALBERT W.: *Sugar pine and western yellow pine in California.* Bul. 69, U. S. Forest Service, Washington, D. C., 1906, pp. 42.

LARSEN, LOUIS T., AND T. D. WOODBURY: *Sugar pine.* Bul. 426, U. S. Dept. Agr., 1916, pp. 40.

6. Piñon. This is one of five species of small trees of southwestern U. S. that are better known for their seeds, piñon nuts, than for their wood, which is used only locally. The trees are sometimes known as the Foxtail and Nut Pine group.

HELLER, A. A.: The nut pine. *Muhlenbergia* 5: 31–35, 1909.

PHILLIPS, F. J.: A study of piñon pine. *Botanical Gazette* 48: 3: 216–223, Sept. 1909.

7. Norway Pine. This species, often called Red Pine, is associated with *P. strobus,* especially in the northern part of its range,

and the lumber of the two is often sold together as Northern Pine. Its ray structure characterizes also one Asiatic and two European Pines, which sometimes are planted for decorative and forestry purposes in northeastern U. S., namely, *P. densiflora* S. & Z. (Japanese Red Pine), *P. sylvestris* L. (Scots Pine), and *P. laricio* Poir. (Austrian Pine).

Woolsey, T. S., Jr., and H. H. Chapman: *Norway pine in the Lake States.* Bul. 139, U. S. Forest Service, Dec. 1914, pp. 42.

Jack Pine. This tree (*Pinus Banksiana* Lam.) has a limited range in the U. S. from Maine to Minnesota, but is extensively distributed in Canada east of the Rocky Mountains. Because of its poor timber form it has only in recent years become of commercial importance. The wood resembles Norway Pine (but has the ray structure of the Yellow Pines), and the better grade of the lumber is often sold in mixture with that species and used for the same purposes. Most of the logs are too small or knotty to make good lumber, hence the timber is principally employed for paper pulp and railway crossties (treated).

Anonymous: *Jack pine.* Tree pamphlet No. 7, Forestry Branch, Dept. Interior, Ottawa, Canada, 1925, pp. 7.

Sterrett, W. D.: *Jack pine.* Bul. 820, U. S. Dept. Agr., 1920, pp. 47.

8. Lodgepole Pine. This species ranges from Alaska to California and New Mexico. It is at its best in the Rocky Mountains, and the form there is sometimes considered a distinct variety or even a different species. The trees are usually small and the timber is used mostly locally for railway crossties, mine props, etc., and only to a small extent for lumber.

Anonymous: American forest trees: Lodgepole pine. *Hardwood Record* (Chicago) 35: 2: 23–24, Nov. 10, 1912.

Kienholz, Raymond: Effect of environmental factors on the wood structure of lodgepole pine, *Pinus contorta* Loudon. *Ecology* (Washington, D. C.) 12: 2: 354–379, Apr. 1931.

Mason, D. T.: *Utilization and management of lodgepole pine in the Rocky Mountains.* Bul. 234, U. S. Forest Service, July 1915, pp. 54.

9. Ponderosa Pine. This important tree is generally known as Western Yellow Pine and Bull Pine. The white, uniform-textured sapwood, until recently marketed as California, Arizona, or New Mexico White Pine, is used for sash, doors, siding, etc., but it is inferior to true White Pine heartwood in resistance to blue stain and decay. Lumber from northwestern U. S. was formerly

sold under the trade name of Pondosa Pine. The appearance and the properties of the lumber are subject to wide variation. Timber of *Pinus Jeffreyi* Oreg. Com. (Jeffrey Pine) of California is sold with *P. ponderosa* without distinction.

ANONYMOUS: *Pondosa pine; its properties, uses, and grades.* Pub. by Western Pine Mfgrs. Assn., Portland, Oregon, 1931, pp. 80.

HANZLIK, E. J.: Trees; a study for lumbermen. Western yellow pine. *Four L Lumber News* (Portland, Oregon) 18: 19: 6–7, July 1, 1926.

MUNGER, T. T.: *Western yellow pine in Oregon.* Bul. 418, U. S. Dept. Agr., Feb. 1917, pp. 48.

ZIMMERMANN, C. W.: *Tests of western yellow pine car sills, joists, and small clear pieces.* Bul. 497, U. S. Dept. Agr., 1917, pp. 16.

10. Southern Yellow Pine. This collective term includes several species of the southeastern U. S., of which the most important are *Pinus palustris* Mill. (Longleaf), *P. echinata* Mill. (Shortleaf), *P. taeda* L. (Loblolly or North Carolina Pine), *P. caribaea* Mor. (Slash Pine), and *P. rigida* (Mill.), var. *serotina* (Michx.) Loud. (Pond Pine). The range of variation of the wood of a single species as a result of environmental factors is often as great as that exhibited by the woods of the different species, hence specific distinctions based on anatomy alone are often impossible. Wood of high density is preferred for heavy construction, while the lighter timber is used mostly for planing-mill products.

" There are no fundamental differences among the Southern Pines which make all the wood of one species preferable to all of the wood of another for any given purpose. The dense wood of any Southern Pine has practically the same strength and other characteristics as the dense wood of any other Southern Pine, and the lighter-weight pieces are more or less alike. In tests at the Forest Products Laboratory, Longleaf and Slash Pines have been found to have somewhat higher average strength properties than Shortleaf, Loblolly, and Pond Pines, but dense pieces of the latter species were found to be stronger than the average pieces of the former. Aside from defects, density can be taken as the factor that determines the suitability of any piece of Southern Pine for structural purposes. It is easily determined by visual methods, and structural timbers are now being classified and sold under density specifications." — From Technical Note No. 214, U. S. Forest Products Laboratory, 1925.

The export trade name for Southern Yellow Pine is Pitch Pine,

but this should not be confused with the tree commonly known in the U. S. as Pitch Pine (see below).

Anonymous: *American pitch pine and its uses.* Trade Promotion Ser. No. 119, U. S. Dept. Commerce, Washington, D. C., 1931, pp. 53.

Betts, H. S.: *Properties and uses of the southern pines.* Cir. 164, U. S. Forest Service, 1909, pp. 30.

Mohr, Charles, and Filibert Roth: *The timber pines of the southern United States, together with a discussion of the structure of their wood.* Bul. 13 (rev. ed.), U. S. Div. Forestry, 1897, pp. 160.

Record, Samuel J.: Southern yellow pine for structural purposes. *American Architect* (New York), Apr. 11, 1917, pp. 223–228.

11. Longleaf Pine. *Pinus palustris* is a large, well-formed tree generally confined to a belt rarely more than 125 miles wide along the coast of the Atlantic and Gulf States from southeastern Virginia into eastern Texas. *P. caribaea* Mor. (Slash Pine) occurs further south and is the principal timber pine of Central America. Its wood is usually coarse grained and frequently more resinous than Longleaf. Wood saturated with resin (Fat Pine) makes excellent fuel and kindling and is the source of wood distillates; owing to its durability it is used for fence posts and railway crossties without preservative treatment. The trees of both species are the principal American sources of naval stores.

Buttrick, P. L.: Commercial uses of longleaf pine. *American Forestry* (Washington, D. C.) 21: 261: 896–908, Sept. 1913.

Fernow, B. E.: *Timber physics. Part II. Results of investigations on longleaf pine.* Bul. 8, U. S. Div. Forestry, 1893, pp. 92.

Koehler, Arthur: A visual method of distinguishing longleaf pine. *American Lumberman* (Chicago) 2104: 34–35, Sept. 11, 1915.

Mattoon, W. R.: *Longleaf pine.* Bul. 1061 (rev. ed.), U. S. Dept. Agr., Aug. 1925, pp. 67.

Mattoon, W. R.: The slash pine. *American Forestry* 23: 279: 158–160, March 1917.

Mattoon, W. R.: *Slash pine.* Farmers' Bul. 1256 (rev. ed.), U. S. Dept. Agr., 1931, pp. 52.

12. Shortleaf Pine. *Pinus echinata* (Shortleaf Pine) and *P. taeda* L. (Loblolly or Old Field Pine) have much the same general range, though that of the first extends further to the north and west. Where the two grow together Shortleaf occupies the drier sites and Loblolly the wet lands. Under similar condition of growth, the woods of the two are not distinguishable. Both, and especially Loblolly, quickly take possession of abandoned fields, and the timber is coarse grained and knotty. The timber commonly sold as North Carolina Pine is principally *P. taeda;* that known as Arkansas Soft Pine is mostly *P. echinata.*

Anonymous: Commercial uses of shortleaf pine. *American Forestry* 29: 273: 517–520, Sept. 1916.
Ashe, W. W.: *Loblolly or North Carolina pine.* Bul. 24, North Carolina Geological and Economic Survey, Raleigh, 1915, pp. 176.
Davis, E. M.: Shortleaf pine; the lumber-making qualities of second-growth and virgin-growth timber. *Southern Lumberman* (Nashville, Tennessee) 137: 1770: 309–310, 312, Dec. 15, 1929.
Detwiler, S. B.: Shortleaf pine. *American Forestry* 22: 273: 513–520, Sept. 1916.
Mattoon, W. B.: *Shortleaf pine; its economic importance and forest management.* Bul. 308, U. S. Dept. Agr., Nov. 1915, pp. 67.
Zon, Raphael: *Loblolly pine in eastern Texas.* Bul. 64, U. S. Forest Service, 1905, pp. 53.

Pitch Pine. The Pitch Pine (*Pinus rigida* Mill.) is a medium-sized to large, often poorly formed tree distributed through New England and New York southward to Georgia and eastern Tennessee. The lumber has been used for a long time locally for general construction and box boards, and an undeterminable amount is sold in mixture with Shortleaf and North Carolina Pine. Its structure is that of the Yellow Pine group.

Illick, J. S., and J. E. Aughanbaugh: *Pitch pine in Pennsylvania.* Research Bul. 2, Pa. Dept. Forests and Waters, Harrisburg, 1930, pp. 108.

13. Douglas Fir. This is the most important timber tree in western North America, with a range exceeding 2000 miles north and south and approaching 1000 miles east and west. It is most abundant and attains its largest size not far from sea level in southern British Columbia and western Washington and Oregon, forming, either alone or in mixture with Western Hemlock, very dense forests that yield from 35,000 to 60,000 board feet per acre, exceptionally 100,000 feet or even more. It is exceeded in stature only by the Sequoias of California. The timber is similar to Southern Pine in its properties and uses, and also in its variability; that from the coastal region is finer grained, more uniform textured, and lighter in color than that of the mountain and intermountain region. It often is known simply as Fir in American markets, and usually as Oregon Pine (sometimes shortened to Oregon) in the export trade.

Anonymous: *American Douglas fir and its uses.* Trade Promotion Ser. No. 87, U. S. Dept. Commerce, 1929.
Cline, McGarvey, and J. B. Knapp: *Properties and uses of Douglas fir.* Bul. 88, U. S. Forest Service, 1911, pp. 75.
Detwiler, S. B.: Douglas fir. *American Forestry* 22: 266: 67–75, Feb. 1916.

Grondal, B. L.: *Durable Douglas fir.* West Coast Lumber Trade Extension Bureau, Seattle, Washington, 1926, pp. 32.
Hanzlik, E. J.: Trees; a study for lumbermen. Douglas fir. *Four L Lumber News* 8: 1: 14–15, 27, Jan. 1, 1926.
Lee, H. N.: *Canadian woods for structural timbers.* Bul. 59, For. Branch. Dept. Interior, Canada, 1917, pp. 44.
Record, Samuel J.: Douglas fir. *American Architect* (New York) 112: 2195: 329–333, Nov. 7, 1917.
Sterns, R. W.: *Canadian Douglas fir; its mechanical and physical properties.* Bul. 60, For. Branch, Dept. Interior, Ottawa, Canada, 1918, pp. 84.
Williams, J. S.: Commercial uses of Douglas fir. *American Forestry* 22: 266: 69–75, Feb. 1916.

14. Western Larch. The distribution of this species is very limited, its center being northern Idaho. It makes its best growth on well-drained soils, where it attains a height of 100–180 feet, exceptionally over 200, and a diameter of 2–3 feet, rarely 4–6 feet. It sometimes forms open, pure stands, but usually is in mixture with other trees such as Western White Pine, Western Red Cedar, Douglas Fir, and sometimes with Western Yellow Pine. The wood is of general utility and has many properties in common with Douglas Fir, with which it often is sold in mixture.

Anonymous: American forest trees. Western larch. *Hardwood Record* (Chicago) 35: 11, 20–21, March 25, 1913.
Anonymous: *Larch; its properties, uses, and grades.* Pub. by Western Pine Mfgrs. Assn., Portland, Oregon, 1931, pp. 48.
Hanzlik, E. J.: Trees; a study for lumbermen. Western larch. *Four L Lumber News* 8: 34: 8, 32–33, Dec. 1, 1926.
Johnson, R. P. A., and M. I. Bradner: *Properties of western larch and their relation to the uses of the wood.* Technical Bul. 285, U. S. Dept. Agr., March 1932, pp. 93.

15. Tamarack. This species has a very extensive range from New England and the Lake States northward through Canada to Alaska, but the trees are mostly small because of the unfavorable conditions of growth. It is most abundant in sphagnum swamps and muskegs, either in pure stands or in association with Black Spruce, but the larger trees grow in better-drained soil where they attain a height of 50–75 feet and a diameter of 14–20 inches, occasionally more. The timber is used chiefly in the round for poles, posts, and railway crossties. The European Larch (*Larix europaea* DC.) is planted for shade and forestry purposes to some extent in eastern U. S.

Ross, A. H. D.: Commercial importance of tamarack. *Canadian Lumberman and Woodworker* 35: 15: 36–37, Aug. 1, 1915.

16. Eastern Spruce. A general term for the wood of three species, widely distributed throughout the northeastern U. S. and Canada. *Picea rubra* (Red Spruce) extends from the Maritime Provinces and eastern Quebec through New England and New York to the southern Appalachians. *P. glauca* (White, Cat, or Skunk Spruce) extends from Alaska and the Arctic Ocean through Canada to the Atlantic and southward into New England and the Lake States. *P. mariana* (Black Spruce) has much the same range as the latter, but extends farther south along the mountains into Virginia. The woods are commonly used without distinction as to species for paper pulp and lumber for building purposes, boxes, and food containers, and sounding-boards of musical instruments. The principal European timber imported for pulp is *P. excelsa* Link (Norway Spruce).

Anonymous: Commercial uses of red spruce. *American Forestry* 22: 276: 707–711, Dec. 1916.

Anonymous: *White spruce.* Tree pamphlet No. 2, For. Branch, Dept. Interior, Ottawa, Canada, 1923, pp. 7.

Buttrick, P. L.: The red spruce. *American Forestry* 22: 276: 705–711, Dec. 1916.

Murphy, Louis S.: *The red spruce; its growth and management.* Bul. 544, U. S. Dept. Agr., 1917, pp. 100.

17. Engelmann Spruce. This species grows mostly at high altitudes in the Rocky Mountains from Canada to Arizona and New Mexico. It is at its best in the inland mountainous region of British Columbia and the east slopes of the Rocky Mountains in Alberta. The lumber is not extensively used, but is suitable for much the same purposes as that of the other species.

Hanzlik, E. J.: Engelmann spruce and lodgepole pine. *Four L Lumber News* 9: 19: 8, 40–41, July 1, 1927.

Hodson, E. R., and J. H. Foster: *Engelmann spruce in the Rocky Mountains.* Circ. 170, U. S. Forest Service, 1910, pp. 23.

Sudworth, George B.: *The spruce and balsam fir trees of the Rocky Mountain region.* Bul. 327, U. S. Dept. Agr., 1910, pp. 43.

18. Sitka Spruce. This species, also known as Tideland Spruce, is a large and important timber tree of the Pacific Coast, growing at low altitudes near the ocean from Alaska to northern California, usually in association with Western Hemlock in Alaska and, farther south, with Douglas Fir and Western Red Cedar also. In 1922 the total stand was estimated at 40–44 billion board feet, equally divided between Alaska, British Columbia, and the states of Wash-

ington, Oregon, and California. The timber varies greatly in rate of growth, that from the outer part of old trees being of fine and uniform grain, but likely to be brittle. It came into prominence during the World War because of its employment in airplane manufacture. It is now extensively used for building purposes (except heavy construction) and in planing-mill, box, and crate industries.

Anonymous: *Sitka spruce.* Pub. by West Coast Lumber Trade Extension Bureau, Seattle, Washington, 1927, pp. 16.

Brown, L. L.: *Canadian Sitka spruce; its mechanical and physical properties.* Bul. 71, For. Branch, Dept. Interior, Ottawa, Canada, 1921, pp. 39.

Cary, N. L.: *Sitka spruce; its uses, growth, and management.* Bul. 1060, U. S. Dept. Agr., May 1922, pp. 38.

Hanzlik, E. J.: Trees; a study for lumbermen. Sitka spruce. *Four L Lumber News* 8: 25: 7, 39–40, Sept. 1, 1926.

19. Fir. The range of Balsam Fir coincides rather closely with that of the White and the Black Spruces, though not extending so far to the northwest in Canada. The heaviest commercial stands are in Quebec and Ontario. The trees are mostly small, and the principal use of the timber is, in mixture with Spruce, for the manufacture of paper pulp. The lumber is employed as a substitute for Spruce, though usually considered inferior to that species. The Balsam Fir of the high mountains of Virginia, etc., is *Abies Fraseri* (Pursh) Poir.

The White Firs become very large and their woods are white, often coarse grained, and rather weak and brittle. *Abies grandis* grows in the northwestern U. S., preferring moist bottomlands. *A. concolor* occurs in the southern Rocky Mountains, but attains its best development in the mountains of California. The lumber is not extensively used and sometimes is sold as Balsam Fir. In the same general category is the Silver Fir, *A. amabilis,* a large, soft-wooded tree at its best at moderate elevations in British Columbia, Washington, and northern Oregon. Lumbermen locally sometimes call it Larch.

A. nobilis occurs in Washington, Oregon, and northern California, and *A. magnifica* in California and southern Oregon. They are large trees and their wood is considerably darker and heavier than that of the other Firs. Noble Fir lumber is sometimes sold as Larch. Two other western species in this category are the Alpine Firs, *A. lasiocarpa* (Hooker) Nutt. and *A. arizonica* Merr.

HANZLIK, E. J.: Trees; a study for lumbermen. The balsam firs. *Four L Lumber News* 9: 1: 9, 32, Jan. 1, 1927; 9: 4: 10, 31, 38, Feb. 1, 1927.

SUDWORTH, GEORGE B.: *The spruce and balsam fir trees of the Rocky Mountain region.* Bul. 327, U. S. Dept. Agr., 1916, pp. 43.

THOMPSON, W. P.: Ray tracheids in *Abies*. *Botanical Gazette* 53: 4: 331–338, April 1912.

ZON, RAPHAEL: *Balsam fir.* Bul. 55, U. S. Dept. Agr., 1914, pp. 68.

20. Hemlock. Eastern Hemlock is a medium-sized to large tree of southeastern Canada, the Lake States, northeastern U. S., and the Appalachians. Formerly the only commercial use for the tree was as a source of tanbark, but later the timber became important for the cheaper grades of paper pulp and lumber for rough construction and boxes. The wood is brittle, splintery, and frequently cross grained.

Western, or West Coast, Hemlock is a tall, well-formed tree in the mixed forests along the Pacific Coast from Alaska to northern California, and extending inland to western Montana. The lumber has been slow in attaining a market under its own name, largely because of the dominance of Douglas Fir and the poor reputation of Eastern Hemlock. It is suitable for all but the heaviest kinds of construction work and is the most important pulpwood in the Pacific Northwest. The total estimated stand of the timber is 214 billion board feet, located as follows: Alaska, 63; British Columbia, 64; Washington, 60; Oregon, 25; Idaho, Montana, California, 2.

ANONYMOUS: *Eastern hemlock* and *Western hemlock.* U. S. Forest Service, June 1929, pp. 3 and 5, resp.

ALLEN, E. T.: *The western hemlock.* Bul. 33, U. S. Bu. Forestry, 1902, pp. 55.

FROTHINGHAM, E. H.: *The eastern hemlock.* Bul. 152, U. S. Dept. Agr., 1915, pp. 43.

HANZLIK, E. J.: Trees; a study for lumbermen. Western hemlock. *Four L Lumber News* 8: 10: 6–7, 38, April 1, 1926.

HANZLIK, E. J., AND H. B. OAKLEAF: Western hemlock; its forest characteristics, properties, and uses. *The Timberman* (Portland, Oregon) 15: 12: 25–33, Oct. 1914.

JOHNSON, R. P. A., AND W. H. GIBBONS: *Properties of western hemlock and their relation to the uses of the wood.* Technical Bul. 139, U. S. Dept. Agr., 1929, pp. 62.

21. Redwood. This tree, often of gigantic size, is of very limited distribution, being at its best in the fog belt along the Pacific slope of the Coast Range in northern California. The heartwood is highly resistant to decay and insects and is extensively used for

siding, trim, sash and doors, porches, greenhouses, shingles, silos, flumes, fence posts, and other purposes where great strength is not required.

The Bigtree, *Sequoia Washingtoniana* (Winslow) Sudw. or *S. gigantea* Decaisne, is an immense California tree limited to about 26 scattered groves, with a few hundred to several thousand trees each. The wood is similar to Redwood, but usually is more deeply colored, finer grained, and weaker.

Anonymous: *Report on the big trees of California.* Bul. 28, U. S. Div. Forestry, 1900, pp. 30.

Anonymous: Redwood lumber and its uses. *American Forestry* 22: 270: 328–332, June 1916.

Campbell, F. H.: The legend and facts of California redwood. *American Lumberman* (Chicago) 2829: 51–53, 65, Aug. 3, 1929.

Fisher, Richard T., et al.: *The redwood.* Bul. 38, U. S. Bu. Forestry, 1903, pp. 40.

Hall, W. R., and Hu Maxwell: *Uses of commercial woods of the United States. I. Cedars, cypresses, and sequoias.* Bul. 95, U. S. Forest Service, 1911, pp. 57–62.

Gordon, Marjorie: Ray tracheids in *Sequoia sempervirens. New Phytologist* 11: 1: 1–7, Jan. 1912.

22. Southern Cypress. A large tree common in the swamps and lowlands of southeastern U. S. Being deciduous, it is often called Bald Cypress. It is not a true Cypress (*Cupressus*), but is close to *Sequoia* botanically and in the properties and uses of the wood. The lumber is employed for general construction, especially where durability is required. Special uses are interior trim, greenhouses, silos and vats, burial caskets, posts, poles, and railway crossties. The heartwood of the living tree is subject to the attacks of a gallery-making fungus, and the lumber so infected is said to be "pecky" or "peggy." Trees growing in permanently wet places develop leafless conical projections from the roots; the wood of these "knees," as they are called, is exceedingly light and soft.

The lumber is sold under a variety of trade names, which refer to the color of wood or the locality of growth. The trees of the deep swamps in the coastal districts near tidewater (coast type) yield a reddish or at times almost black heartwood, variously known as Red Cypress, Tidewater Red Cypress, Louisiana Red Cypress, Gulf Red Cypress, Gulf Coast Red Cypress, or Black Cypress. On the other hand, the trees in the inland and upland sections of the range (inland type) usually have lighter-colored heartwood and a higher percentage of sapwood than the coast

type; the wood from such trees is known as Yellow Cypress or White Cypress. The color distinctions between the two general types of wood are evidently associated with site conditions, especially acidity and drainage of the soil. It is generally conceded that the Red or Black Cypress is superior in durability, although even the light-colored heartwood has marked resistance to decay.

ANONYMOUS: *American cypress and its uses.* Trade Promotion Ser. 141, U. S. Dept. Commerce, 1932, pp. 28.

DETWILER, S. B.: The bald cypress. *American Forestry* 22: 274: 577–585, Oct. 1916.

MATTOON, W. R.: *Southern cypress.* Bul. 272, U. S. Dept. Agr., 1915, pp. 74.

RECORD, SAMUEL J.: The southern cypress. *American Architect* (New York), Oct. 18, 1916, pp. 247–254.

ROTH, FILIBERT: *Progress in timber physics. Bald cypress.* Cir. 19, U. S. Div. Forestry, 1898, pp. 24.

23. Cedar Group. This is a general term applied in America to several kinds of trees and their fragrantly scented woods. The true Cedars (*Cedrus*), such as the famed Cedar of Lebanon, the Atlas Cedar of northern Africa, and the Deodar of India, are Pine-like in their structure. Spanish Cedar, of which the best cigar boxes are made, is of a tropical dicotyledonous tree (*Cedrela*) that is closely related to true Mahogany (*Swietenia*).

HALL, W. R., AND HU MAXWELL: *Uses of commercial woods of the United States. I. Cedars, cypresses, and sequoias.* Bul. 95, U. S. Forest Service, 1911, pp. 11–40.

ROSS, A. H. D.: The commercial importance of cedar. *Canadian Lumberman and Woodworker* 35: 13: 26–28, July 1, 1915.

24. Alaska Cedar. This medium-sized to large tree occurs along the Pacific Coast from Alaska into Oregon, being most highly developed in southern Alaska and British Columbia, and is variously known as Sitka, Yellow, Nootka, and Alaska Cypress, and as Yellow Cedar. The estimated stand is about 10 billion board feet. The annual lumber production has been small and mostly for use locally for interior finish, furniture, and hulls of small boats. Alaska Indians prefer it for canoe paddles.

ANONYMOUS: Properties and uses of Alaska cypress. *The Timberman* (Portland, Oregon) 30: 11: 39–40, Sept. 1929.

HIBBERSON, R. W.: Yellow cedar in British Columbia. *The Timberman* 22: 12: 138, Oct. 1921.

25. Port Orford Cedar. A large tree of very limited range and of commercial importance only in a strip 20–25 miles wide along

the Pacific Coast in Coos and Curry Counties in southwestern Oregon. The total stand is about 500 million board feet. The principal uses of the lumber are for sash and doors, small boats, storage battery separators, match sticks, and house siding. Alternative names are Lawson's Cypress, Oregon Cedar, and White Cedar.

ANONYMOUS: Port Orford cedar; its properties and uses. *The Timberman* 30: 3: 49–80, Jan. 1929.
SMITH, H. H.: Uses of Port Orford cedar. *Hardwood Record* (Chicago) 37: 4: 30–31, Dec. 10, 1913.

26. Incense Cedar. A medium-sized tree of California and southern Oregon. The estimated stand is less than 10 billion feet, and most of the large trees have been attacked by a gallery-producing fungus similar to that causing "peckiness" in *Taxodium.* Most of the timber is consumed locally for building purposes, posts, and poles. A limited amount of the finest grade is used as a substitute for *Juniperus* in making lead pencils.

MITCHELL, J. A.: *Incense cedar.* Bul. 604, U. S. Dept. Agr., 1918, pp. 40.

27. Eastern Red Cedar. *Juniperus virginiana* is a small tree distributed scatteringly over almost the entire eastern half of the U. S. and extending into Nova Scotia and New Brunswick. *J. lucayana* grows in Florida and parts of adjacent states. Most of the timber is used for fence posts. The principal uses for the lumber are clothes chests, closet linings, and lead pencils. The tree is rapidly disappearing as a source of commercial wood. The largest remaining stands are in the mountains of Kentucky, Tennessee, and Alabama.

ANONYMOUS: *Eastern red cedar.* U. S. Forest Service, Feb. 1928, pp. 3.
BROWN, L. E.: Tennessee red cedar. *Southern Lumberman* (Nashville, Tennessee) 125: 1629: 201–202, Dec. 18, 1926.
MOHR, CHARLES: *Notes on the red cedar.* Bul. 31, U. S. Bu. Forestry, 1901, pp. 37.
WHITE, L. L.: *Production of red cedar for pencil wood.* Cir. 102, U. S. Forest Service, 1907, pp. 19.

28. Western Red Cedar. This is a very large tree growing principally in a belt along the Pacific Coast from southern Alaska to northern California and extending inland to western Montana. It is at its best in western Washington and British Columbia. The estimated stand in the United States is about 50 billion board feet. About two-thirds of all the timber cut goes into shingles,

supplying about 90 per cent of all used in the U. S. The lumber is used for siding, interior trim, tanks, boats, porch columns, greenhouses, and other purposes where durability rather than strength is a requisite. Small trees are much used for telegraph and telephone poles and fence posts.

Detwiler, S. B.: Western red cedar. *American Forestry* 22: 267: 131-137, March 1916.

Flavelle, Aird: British Columbia red cedar. *Canadian Lumberman and Woodworker* 35: 20: 30–32, Oct. 15, 1915.

Hanzlik, E. J.: Trees; a study for lumbermen. Western red cedar. *Four L Lumber News* 8: 28: 11, 38, Oct. 1, 1926.

Keith, L. P.: Red cedar possibilities in general construction and industrial uses. *West Coast Lumberman* (Seattle-Tacoma) 45: 541: 24–24a, Apr. 15, 1924; 45: 542: 50, 224, May 1, 1924.

Knapp, J. B., and A. G. Jackson: Western red cedar in the Pacific Northwest. *West Coast Lumberman* 25: 296: 34–35, 37–40, Feb. 1; 25: 298: 62–64 et seq., March 1, 1914.

Wyckoff, H. P.: Commercial uses of western red cedar. *American Forestry* 22: 267: 134–137, March 1916.

29. Northern White Cedar. A small tree of the swamps in southeastern Canada, the Lake States, and the Atlantic region to New Jersey and along the mountains southward to North Carolina. Its principal use is in the round for fence posts and telephone poles; a limited amount of lumber is used for making small boats and canoes. When used for decorative planting the tree is usually called Arborvitae.

Anonymous: *Northern white cedar.* U. S. Forest Service, 1927, pp. 3.

30. Southern White Cedar. A medium-sized to large tree, often in pure stands in the Atlantic and Gulf coastal swamps and estuaries from southern Maine to northern Florida and southeastern Louisiana. The present centers of production are southern New Jersey, eastern North Carolina, and the Gulf Coast. The principal uses, besides posts and poles, are for boat-planking, tanks, shingles, woodenware, and miscellaneous planing-mill products.

Harlow, W. M.: The effect of site on the structure and growth of white cedar. *Ecology* (Washington, D. C.) 8: 4: 453–470, Oct. 1927.

Korstian, C. F., and W. D. Brush: *Southern white cedar.* Technical Bul. 251, U. S. Dept. Agr., Sept. 1931, pp. 76.

31. Pacific Yew. A small tree of poor timber form occurring scatteringly in the undergrowth of high forests from southern

Alaska along the Coast Ranges of British Columbia, Washington, and Oregon (where it attains its best dimensions) into central California; also in northern Idaho and adjacent regions. Principal uses of the wood are for archery bows, small cabinet work, articles of turnery and carving. *Taxus floridana* Chapm. (Florida Yew) is a small bushy tree of very limited distribution in Florida. *T. canadensis* Willd. (American Yew or Ground Hemlock) is a low, straggling bush in evergreen forests in New England, the Lake States, and eastern Canada. The Yew of Europe is *T. baccata* L., and that of eastern Asia is *T. cuspidata* S. & Z.

32. Tumion or **Torreya.** Of this genus there are four species, one in Florida and Georgia, one in California, and two in eastern Asia. The California Nutmeg is a small to rather large tree of infrequent occurrence along mountain streams. Stinking Cedar is a small tree, too rare to be of commercial importance. The woods are included in the key only because of their scientific interest.

33. Golden Chinquapin. A stout, medium-sized to large tree of infrequent occurrence from southwestern Washington to southern California; at its best in the coast valleys of northern California. Used locally for much the same purposes as Birch. There is another California species, a low alpine shrub, and there are numerous species in southeastern Asia.

34. Chestnut. A large tree, formerly of wide distribution in the eastern half of the U. S. and of high commercial importance from southern New England to the southern Appalachians, but now eradicated from much of its range and threatened with destruction in the remainder as a result of a blight caused by a parasitic fungus. The principal uses are for railway crossties, telegraph and telephone poles, piling, fence posts, interior trim, common furniture, cores for veneers, shingles, tannin, and paper pulp. A smaller species, *Castanea pumila* Mill., occurs in the southern states, esp. southern Arkansas and eastern Texas. Its wood is mostly harder, heavier, and of slower growth than the other, but in general the structure, properties, and uses of the two are the same. Other species occur in the Mediterranean region and Asia.

Ashe, W. W.: *Chestnut in Tennessee.* Bul. 10, Tennessee Geol. Survey, Nashville, 1912, pp. 35.

Buttrick, P. L.: Chestnut as a pulp wood. *Pulp and Paper Magazine* (New York), Nov. 1, 1915, pp. 554–555.

Detwiler, S. B.: The American chestnut tree. *American Forestry* 211: 262: 957–960, Oct. 1915.

35. Oak. There are hundreds of species, varieties, and hybrids of Oak trees in the temperate regions of the northern hemisphere and high altitudes within the tropics. They vary in size from low shrubs to stately forest trees. The timber is extensively employed for innumerable purposes ranging from fuel, fence posts, and railway crossties to cooperage, heavy construction, interior trim, flooring, and all grades of furniture to the finest of cabinet work. The woods have many properties in common and are separable into two distinct groups — the White, and the Red or Black Oaks — which correspond to important botanical differences in the trees. The wood of the deciduous trees is ring-porous and that of the evergreen species diffuse-porous. The most distinctive single feature is the large rays, but these are occasionally absent or widely separated. There are about 50 species of Oak trees in the U. S., and about 35 species and varieties are of more or less commercial importance. The bulk of the timber comes from the central hardwood region, and the best remaining first-growth stands are in the southern Appalachians.

Abromeit, Johannes: *Über die Anatomie des Eichenholzes.* Berlin, 1884, pp. 77.

Bailey, I. W.: Notes on the wood structure of the Betulaceae and Fagaceae. *Forestry Quarterly* (Ithaca, N. Y.) 8: 2: 178–190, June 1910.

Record, Samuel J.: An easy identification of the oaks. *Hardwood Record* (Chicago) 39: 5: 23, Dec. 25, 1914.

Record, Samuel J.: The king of woods. *House and Garden* (New York), Aug. 1925, pp. 70–71, 92–94.

Ross, A. D. H.: The commercial importance of oak. *Canadian Lumberman and Woodworker* 35: 17: 28–30, Sept. 1, 1915.

36. Red Oak Group. The principal commercial species are as follows: (Northern) Red Oak, *Quercus borealis maxima* (Marsh.) Ashe, formerly included under *Q. rubra* L.; Black Oak, *Q. velutina* LaM.; Southern Red Oak, *Q. rubra* L., formerly *Q. digitata* (Marsh.) Sudw.; Swamp Red Oak, *Q. rubra pagodaefolia* (Ell.) Ashe; Pin Oak, *Q. palustris* Muench.; Water Oak, *Q. nigra* L.; Texas Red Oak, *Q. texana* Buckley; Willow Oak, *Q. phellos* L. The timber of this group is more porous and less durable than that of the White Oaks and is not suitable for the best class of tight cooperage or for use, without preservative treatment, where exposed to decay; it generally is also less highly esteemed for fine furniture, flooring, and interior trim.

37. White Oak Group. The principal commercial species are as follows: White Oak, *Quercus alba* L.; Post Oak, *Q. stellata* Wang.; Swamp Chestnut Oak, *Q. prinus* L., formerly *Q. Michauxii* Nutt.; Overcup Oak, *Q. lyrata* Walt.; Swamp White Oak, *Q. bicolor* Willd., formerly *Q. platanoides* (LaM.) Sudw.; Bur Oak, *Q. macrocarpa* Michx.; Chinquapin Oak, *Q. Muehlenbergii* Engelm., formerly *Q. acuminata* (Michx.) Houba; Chestnut Oak, *Q. montana* Willd., formerly *Q. prinus* of authors, not Linnaeus. The Oak timber imported from Europe is mostly *Q. robur* L. White Oak is considered the only satisfactory timber for beer kegs, spirit and wine barrels, etc. The heartwood is more durable, has a more attractive appearance, and usually is finer textured and easier to manipulate in manufacture than that of the Red Oaks, though much depends upon the conditions of growth and age of the trees. In *Quercus montana* tyloses are not abundant. In southern White Oaks of rapid growth the transition from large to small pores is gradual instead of abrupt, but the late-wood pores are thin walled and too numerous to be readily counted even though some of them are fairly distinct under the lens.

Detwiler, S. B.: The American white oak. *American Forestry* 22: 265: 3–11, Jan. 1916.

Foster, H. D., and W. W. Ashe: *Chestnut oak in the southern Appalachians.* Cir. 135, U. S. Forest Service, 1908, pp. 23.

Greeley, W. B., and W. W. Ashe: *White oak in the southern Appalachians.* Cir. 105, U. S. Forest Service, 1907, pp. 27.

Illick, Joseph S.: The white oaks. *American Forestry* 28: 346: 586–592, Oct. 1922.

38. Elm. *Ulmus,* with upward of 20 species, is widely distributed throughout the north temperate zone, except in the western half of North America. Of the six species in the U. S., three are of commercial importance. *U. americana,* the American or White Elm tree, is the most important species, and its range extends over the entire eastern half of the U. S. and adjacent regions of southern Canada. The center of production has shifted from the Lake States to the lower Mississippi Valley. *Ulmus fulva,* called Slippery Elm because of the mucilaginous inner bark, is of scattered occurrence over most of the range of the preceding, though it does not grow so far to the north and west. *Ulmus racemosa,* the Cork or Rock Elm tree, is of limited occurrence in New York, Ohio, Indiana, Kentucky, Illinois, Iowa, Missouri, and portions of adjacent states; it is at its best in the Ohio Valley.

All the foregoing are large trees. *Ulmus alata* Michx., the Wahoo or Winged Elm, is a rather small, often poorly formed tree of the south-central U. S.; its timber is mostly of only local importance.

Elm wood is tough, strong, and laminated, having bands of strong fibers alternating with open layers of vessels, hence it is well suited for bent work. The principal uses are for slack cooperage (including the hoops) and, in the form of veneer, for baskets and crates. The best grades serve much the same purposes as Ash and Hickory for implement frames, vehicle parts (including hubs of wagon wheels), and certain types of furniture.

Brush, W. D.: *Utilization of elm.* Bul. 683, U. S. Dept. Agr., 1916, pp. 43.

Detwiler, S. B.: The American elm. *American Forestry* 22: 269: 259–267, May 1916.

Frothingham, E. H.: Rock elm. *Journal of Forestry* (Washington, D. C.) 16: 7: 834–836, Nov.; 16: 8: 950, Dec. 1918.

Record, Samuel J.: The wood of the elms. *Barrel and Box* (Chicago) 17: 9: 29–30, Nov. 1912.

39. Hackberry. *Celtis*, with many species, is widely distributed in temperate and tropical regions. Six species and eight varieties are known in the U. S., but only two of them are of any commercial importance. They grow in the same general region as the Elm and the lumber is usually sold in mixture.

40. Mulberry. The native Mulberry, often called Red Mulberry, is widely distributed in the hardwood forests of the eastern half of the U. S. It is usually a small tree of scattered occurrence and its timber is used mostly locally for fence posts and small articles of furniture. The White Mulberry of China, *Morus alba* L., and the Black Mulberry of Persia, *M. nigra* L., have been widely planted for their fruit and have become naturalized in many places in the U. S. Their woods are similar in structure and properties to the native species.

41. Osage Orange. A bushy and very thorny tree, native to a few hundred square miles in southern Arkansas, Oklahoma, and northeastern Texas, but widely distributed elsewhere by cultivation, especially for hedges. The principal uses of the timber are for fence posts, insulator pins, treenails, and wheel stock. Formerly used by native Indians for bows, hence the name Bois d'Arc or Bodark. Bark and heartwood contain yellow coloring matter, sometimes employed for dyes.

Kressman, F. W.: Osage orange; its value as a commercial dyestuff. *Journ. Ind. and Eng. Chemistry* (New York) 6: 6: 462–464, June 1914.

Maxwell, Hu: *Utilization of Osage orange.* Pub. by Farm Wagon Dept., National Implement and Vehicle Assn. of U. S. A., 1911, pp. 14.

42. Locust. This medium-sized to large tree, native to the central hardwood region of the U. S. and at its best on the western slopes of the Appalachians in West Virginia, has been widely naturalized by cultivation throughout the whole country east of the Rocky Mountains. When small, the trees are subject to the attacks of a beetle that riddle the wood. The very hard, strong, and durable heartwood is used chiefly for insulator pins, wagon hubs, treenails, fence posts, and mine timbers. In structure and properties it is remarkably similar to Osage Orange. There are two other species and numerous varieties in this country, but they are too small to produce timber of more than local utility.

Cuno, John B.: *Utilization of black locust.* Cir. 131, U. S. Dept. Agr., Oct. 1930, pp. 20.

Detwiler, S. B.: The locusts; identification and characteristics. *American Forestry* 23: 278: 88–93, Feb. 1917.

43. Mesquite. A small tree, often only a shrub with a huge root system, in the southwestern U. S., but much larger in Mexico and southward. Widely planted in warm semi-arid regions in various parts of the world, the wood being valuable for fuel and fence posts, the flowers as a source of honey, and the pods for food for cattle. Wood grown in tropical climates is diffuse-porous. The common name in Latin countries is Algaroba. According to Paul C. Standley (*Trees and shrubs of Mexico*, p. 1657), the scientific name should be *Prosopis chilensis* (Mol.) Stuntz.

Anonymous: Mesquite in semi-arid regions. *Hardwood Record* (Chicago) 39: 10: 13, March 10, 1915.

Craighead, F. C.: *Protection of mesquite cordwood and posts from borers.* Farmers' Bul. 1197, U. S. Dept. Agr., May 1921, pp. 12.

Forbes, R. H.: *The mesquite tree; its products and uses.* Bul. 13, Arizona Agr. Exp. Sta., Tucson, 1895, pp. 26.

Walton, G. P.: *A chemical and structural study of mesquite, carob, and honey locust beans.* Farmers' Bul. 1194, U. S. Dept. Agr., Dec. 1923, pp. 20.

44. Coffee-tree. A large tree of infrequent occurrence in the central hardwood region, but rather widely planted for decorative purposes and generally known as Kentucky Coffee-tree. The name refers to the early use of the beans as a substitute for coffee. In New York and Maryland it is sometimes called Mahogany.

The strong and durable timber is used locally for fuel, posts, railway crossties, bridge timbers, sills, interior trim, and furniture. In some parts of Tennessee the tree is fairly common and the lumber is occasionally marketed as Butternut. There is one other species, in central China.

Record, Samuel J.: Some woods of the pea family. *Hardwood Record* 35: 11: 28–29, March 25, 1913.

45. Honey Locust. A large and very thorny tree, common though nowhere abundant in the Middle West and attaining its best development in southern Indiana and Illinois. The timber is used locally for fuel, fence posts, and poles, and sometimes for hubs and fellies of wagon wheels and for furniture and interior trim. The tree is rather widely planted, especially on the plains, for ornament and in windbreaks. The unarmed variety is preferred for use along streets. There are two other species in the U. S., one along the Gulf Coast and one in Texas, and about 15 others in eastern Asia, tropical West Africa, and south-central South America. The generic name has two spellings — *Gleditsia* and *Gleditschia.*

Anonymous: Honey locust (*Gleditsia triacanthos*). Planting leaflet, U. S. Bu. Forestry, pp. 3. (See also under Coffee-tree.)

46. Sassafras. Usually a small, crooked tree, but sometimes up to 90 feet tall with a trunk nearly 6 feet in diameter; widely distributed over the entire eastern half of the U. S., in the south Atlantic and Gulf States often taking possession of abandoned fields, sometimes in association with Persimmon. Alternative scientific names are *Sassafras officinale* N. & E. and *S. Sassafras* (L.) Karst. The soft, fragrantly scented, durable wood was formerly used for lumber, but now, because of the scarcity of large trees, chiefly in the round for fence posts and rails, poles, and fuel. Occasional logs are sawed into boards and sold as Ash. The small roots and root-bark are rather extensively used for making Sassafras tea. Two other species occur from central China to Formosa.

47. Catalpa. A large tree of very limited natural distribution in the lower Ohio Valley region, mostly on the bottomlands of southern Indiana and Illinois. Widely planted in groves and as shade trees throughout the Middle West. The timber resembles Butternut, but large sizes are too uncommon to be of much eco-

nomic importance. Small trees are principally used for fence posts, but their durability has been overrated. The tree is frequently designated as Hardy Catalpa to distinguish it from another species, *Catalpa bignonioides* Walt., which occurs scatteringly in the southeastern U. S. and is not considered suitable for forest plantations, especially in northern localities, although often grown for ornamental purposes. Other species grow in the West Indies and eastern China.

Green, W. J.: *The hardy catalpa as a farm crop.* Bul. 149, Ohio Agr. Exp. Sta., Wooster, 1904, pp. 69–80.

Hall, W. L.: *The hardy catalpa.* Bul. 37, U. S. Bu. Forestry, 1902, pp. 58.

Record, Samuel J.: *The hardy catalpa.* Pub. 22, Dept. Botany, Wabash College, Crawfordsville, Indiana, 1906, pp. 15.

Roberts, H. F.: *The hardy catalpa.* Bul. 108, Exp. Sta., Kansas State Agr. College, Manhattan, 1902, pp. 99–214.

48. Ash. There are 18 species and 7 varieties of *Fraxinus* in the U. S. and Canada, but the three listed in the key supply all but about 2 per cent of the lumber produced. Woods of the several kinds are marketed under the general name of Ash or else that of the Black Ash tree is called Brown Ash and all the others White Ash. All the commercial species are in the eastern half of the country, except *F. oregona* of the Pacific Coast region. The wood of the Oregon Ash belongs in the White Ash group, but the structure is intermediate. Green Ash (var. of Red Ash) has the widest range, extending in Canada to the Rocky Mountains, but commercial production is mostly in the southern states; the wood of old-growth trees of it and *F. profunda* from continuously wet bottomlands is called Pumpkin Ash because it is very light, soft, and brittle. White Ash is at its best in the central hardwood region. Black Ash is more northern — New England, the Lake States, and southeastern Canada. Ash is not a structural timber, the principal uses including handles of tools (shovels, rakes, hoes, etc., rather than axes, hammers, etc., where Hickory is preferred), butter tubs, bent work, athletic goods, baseball bats, oars. Considerable quantities of lumber are consumed in the manufacture of automobiles, kitchen furniture, and interior trim. Where great strength is a requisite, second-growth timber of the White Ash group is preferred. Much of the lumber used is sapwood; it is perishable in contact with the ground, and stored material is subject to attacks of the powder-post beetle. The principal

European species of Ash is *F. excelsior* L. and that of Japan, *F. mandshurica* Rupr.; both are of the White Ash group.

DETWILER, S. B.: White ash. *American Forestry* 21: 264: 1081–1089, Dec. 1915.

RECORD, SAMUEL J.: The wood of the ashes. *Hardwood Record* 35: 2: 28–29, Nov. 10, 1912.

STERRETT, W. D.: *The ashes; their characteristics and management.* Bul. 299, U. S. Dept. Agr., 1915, pp. 88.

STERRETT, W. D.: *Utilization of ash.* Bul. 523, U. S. Dept. Agr., June 1917, pp. 52.

49. Persimmon. Only two out of over 200 species of *Diospyros* are native to the U. S., one (*D. texana* Sch.) a small tree in southwestern Texas, the other a medium-sized to large tree widely distributed over the southeastern states to the Ohio Valley and having its most northern extension at New Haven, Connecticut. Some of the species are best known for their fruit, others for their timber, the true Ebony, which varies from blue-black to beautifully variegated. The principal use of native Persimmon wood is for the larger-sized shuttles in the textile industry, only straight-grained sapwood, free of all defects, being suitable. Minor uses of the sapwood are heads of golf clubs, handles of small tools, plane blocks, and shoe lasts. A small amount of heartwood lumber is used for furniture, cabinet work, parquet floors, and articles of turnery.

CUNO, JOHN B.: *Utilization of dogwood and persimmon.* Bul. 1436, U. S. Dept. Agr., Sept. 1926, pp. 43.

RECORD, SAMUEL J.: Persimmon wood; its uses and substitutes. *Southern Lumberman* (Nashville, Tennessee) 68: 899: 95–96, Dec. 21, 1912.

50. Hickory. The genus *Hicoria*, or *Carya*, is confined to the temperate region of eastern North America, from the valley of the St. Lawrence River to the highlands of Mexico, and to southern China where one species occurs. The trees are of present commercial importance only in the U. S. Botanists recognize 16 species and 20 varieties in the U. S. at present, but from the standpoint of the wood they are of two groups, namely, the so-called true Hickories (section *Eucarya*) and the Pecan Hickories (section *Apocarya*). The trees of the latter section are more valuable as a source of nuts than for their wood, which is considered inferior in its technical properties. The timber most in demand is sapwood of second-growth trees, and density is much more important than any botanical distinction. The principal uses are handles of axes, hammers, etc., where resistance to shock is important;

implements and machinery; spokes for carriage and automobile wheels; poles and shafts of buggies; pump rods for oil wells; shafts of golf clubs; and many other purposes where straightness of grain and great strength, toughness, resilience, and ease of working are requisites. Sapwood is subject to the attacks of the powder-post beetle. The trade prejudice against heartwood is not justified, as density and freedom from defects are the determining factors of strength.

Boisen, A. T., and J. A. Newlin: *The commercial hickories.* Bul. 80, U. S. Forest Service, 1910, pp. 64.

Detwiler, S. B.: The hickories. *American Forestry* 22: 272: 451–457, Aug. 1916.

Hatch, Charles F.: *Manufacture and utilization of hickory, 1911.* Cir. 187, U. S. Forest Service, 1911, pp. 16.

Kribs, David A.: The wood of *Carya tonkinensis* H. Lecomte. *Tropical Woods* 16: 50–52, Dec. 1, 1928.

51. Walnut. Of the five native species of *Juglans,* only the two listed are of much commercial value, although a limited quantity of lumber is supplied by the others, particularly *J. californica* S. Wats. Black Walnut and Butternut, or White Walnut, are both widely distributed throughout most of the eastern half of the U. S., and the first species, from the time of the earliest settlements, has been one of the foremost American timbers for furniture, cabinet work, and gunstocks. The supply is being maintained through cultivation, both for the timber and the nuts. Butternut has been much less prominent in the market, and the supply is limited. It is used for furniture and interior trim, and general carpentry. Circassian, Italian, French, and English Walnut are all of the same species, *J. regia* L., introduced into Europe from Persia and perhaps originating in China. There are several species in the mountains of tropical America and in Asia.

Baker, F. S.: *Black walnut; its growth and management.* Bul. 933, U. S. Dept. Agr., March 1921, pp. 43.

Brush, W. D.: *Utilization of black walnut.* Bul. 909, U. S. Dept. Agr., Jan. 1921, pp. 89.

Kribs, David A.: Comparative anatomy of the woods of the Juglandaceae. *Tropical Woods* 12: 16–21, Dec. 5, 1927.

Record, Samuel J.: The walnuts and the hickories. *Hardwood Record* 36: 1: 27–29, Apr. 25, 1913.

Record, Samuel J.: The thoroughbred of the woods. *House and Garden* (New York), May 1925, pp. 104, 110, 112.

Sudworth, G. B., and C. D. Mell: Identification of North American walnut woods. *Hardwood Record* 38: 10: 23–26, Sept. 10; 38: 11: 25–29, Sept. 25, 1914.

52. Hop Hornbeam. Usually a low-spreading tree, though often with a rather thick bole, widely distributed throughout the eastern half of North America, though nowhere abundant. It is rarely cut for lumber, but the timber, commonly known as Ironwood, is used locally for many of the same purposes as Hickory. The Hop Hornbeam of southern Europe and Asia Minor is *Ostrya carpinifolia* Scop.

53. Blue Beech. A bushy tree, with a smooth-barked, fluted trunk, widely distributed in the eastern half of North America, but nowhere abundant or of importance except for fuel. There are several species in the northern hemisphere of the Old World, the best known being the Hornbeam (*C. betulus* L.) of Europe and western Asia, whose timber is employed for tool handles, shoe lasts, rollers, and fuel.

54. Holly. There are over 200 species of *Ilex*, mostly shrubs, widely distributed in the temperate and tropical regions of the world. There are several species attaining tree size in the U. S., but the only one of any commercial importance is *I. opaca*, growing all along the Atlantic Coast and in the lower Ohio and Mississippi Valleys. The lumber is used to a limited extent for inlaying, turnery, brush backs, and sometimes stained black to imitate Ebony. The spiny evergreen foliage and the red berries are much used for Christmas decorations. The principal species of central Europe and western Asia is *I. aquifolium* L. In the woods of certain species the fiber-tracheids are not characterized by spiral thickenings.

55. Oregon Myrtle. The single species is a medium-sized or occasionally large tree of southern Oregon, where it is at its best, and in various parts of California. Alternative names are California or Mountain Laurel, Spice-tree, Pepperwood, and Cajeput. The lumber, like that of most of the members of the Lauraceae, is of good quality and working properties and is used to a limited extent for furniture, cabinet work, interior trim, and articles of turnery. The natural color is often darkened by keeping the logs submerged in water for a time.

56. Birch. *Betula*, with 25–30 species, is distributed from the Arctic Circle to Texas in the western hemisphere and to southern Europe, Himalayas, and eastern Asia in the eastern, some species forming extensive forests in northern regions. Of the several American species and varieties, *B. lutea* (Yellow Birch) is by far

the most abundant and most valuable commercially; it occurs in southeastern Canada, the Lake States, New England, and southward through the Appalachians to Georgia; the best stands are in the U. S. near the Canadian border. *B. lenta* (Sweet, Black, or Cherry Birch) ranks second; it ranges from the southern Appalachians, where it attains its largest size, through New England to Ontario and Newfoundland, becoming more abundant northward. The wood of Sweet Birch is somewhat heavier, stronger, and darker colored than Yellow Birch, but the two are sold together simply as Birch; sometimes the heartwood is called Red Birch and the sapwood White Birch; they are much used in the manufacture of furniture, interior trim, flooring, and doors; also for fuel, destructive distillation, and railway crossties (treated). *B. papyrifera* (Paper, Canoe, or White Birch) has an extensive range from Labrador to the Rocky Mountains in Canada and through New England and the Lake States in the U. S., being of chief commercial importance in Maine. Because of its fine and uniform texture and lack of color, White Birch is especially well suited for articles of turnery such as spools, bobbins, dowels, and small handles; it is also used for toothpicks and shoe pegs, and the bark for novelties and formerly for canoes. *B. populifolia* Marsh. (Gray Birch) is a slender, often crooked tree, abundant in New England. Its wood is of the type of the Paper Birch and is used for the same purposes, though chiefly for fuel; it often contains abundant pith flecks. *B. nigra* L. (River or Red Birch) is a common tree of poor timber form along streams near the Atlantic Coast and in the Mississippi and Ohio Valleys. Its coarse-textured, tough, brownish wood is used for slack cooperage and fuel; pith flecks are very common. The western species of Birch from Alaska southward are of little or no commercial importance. The principal Birch of Europe is *B. alba* L.; its wood is of the Paper Birch type. The wood of some of the Japanese species is hard and reddish, being of the class of *B. lenta*.

Anonymous: *Birch.* U. S. Forest Service, Feb. 1928, pp. 6.

Dana, S. T.: *Paper birch in the Northeast.* Cir. 163, U. S. Forest Service, 1909, pp. 37.

Detwiler, S. B.: The birches. *American Forestry* 22: 268: 195–201, April 1916.

Maxwell, Hu: *Uses of commercial woods of the United States; beech, birches, and maples.* Bul. 12, U. S. Dept. Agr., Oct. 1913, pp. 11–32.

Record, Samuel J.: The wood of the birches. *Hardwood Record* (Chicago) 35: 3: 32–33, Nov. 25, 1912, pp. 32–33.

Record, Samuel J.: Birch. *American Architect* (New York), July 25, 1917, pp. 71–74.

57. Maple. *Acer*, with over 60 species, is widely distributed over the northern hemisphere. There are 13 species and several varieties in North America; on a basis of their woods they are divisible into two unequal groups, Hard Maple and Soft Maple. The first consists of *A. saccharum* (Sugar, Hard, or Rock Maple and Sugar Tree) and *A. nigrum* (Black Maple), which some botanists consider only a variety of the other; for all practical purposes they are not distinct species. Hard Maple is by far the most important as well as most abundant, occurring throughout most of the eastern hardwood region of the U. S. and Canada, being at its best near the Great Lakes, and in northern New England and the St. Lawrence Valley. The tree is called Sugar Maple because the sap is sweet in the spring and is an important source of syrup and sugar. The wood is stronger, denser, and more resistant to wear than that of the Soft Maples and accordingly is preferred for flooring in dance halls, bowling alleys, and shops, and for implements and frames of machinery and vehicles where strength is essential. The wood is also attractive, owing to the more conspicuous rays and to special types of figure, such as bird's-eye, curly grain, and fiddle-back mottle. The two principal Soft Maples, *A. rubrum* (Red Maple) and *A. saccharinum* (Silver Maple), have much the same range, though extending farther south, attaining their best development in the lowlands of the Ohio Valley. *A. macrophyllum* Pursh. (Bigleaf, Broad-leaved, or Oregon Maple) grows along the Pacific Coast from Alaska to southern California, attaining its greatest development in Oregon and Washington where a few million feet of its lumber are manufactured annually. The wood belongs to the Soft Maple group, but is more deeply colored and often attractively figured; burls are common. All the foregoing kinds of Maple are used for furniture, interior trim, flooring, cooperage, woodenware, novelties, fuel, distillation wood, and charcoal. *A. Negundo* (Boxelder or Ash-leaved Maple) and its varieties have a combined range covering nearly the whole of the U. S., but nowhere important commercially. Its uses include certain classes of furniture, woodenware, cooperage, and fuel. The coral-red to carmine stain of

common occurrence in the wood is due to the presence of a soluble pigment produced by the colored hyphae of a fungus, *Fusarium negundi* Sherb. There are many kinds of Maple in Japan, some of them yielding valuable timber. The species of Europe are *A. pseudoplatanus* L., *A. campestre* L., and *A. platanoides* L. Both tree and timber of *A. pseudoplatanus* are called Sycamore in England, a name applied in America to *Platanus;* the wood when artificially stained gray is known as Harewood or Silver-grey Wood.

ANONYMOUS: *Sugar maple.* Tree pamphlet 14, Dept. Interior, Ottawa, Canada, 1930, pp. 8.

HUBERT, E. F.: The red stain in the wood of boxelder. *Journ. Agr. Research* (Washington, D. C.) 26: 10: 447–457, Dec. 8, 1924.

JOHNSON, H. M.: *Utilization of bigleaf maple of the Pacific Northwest.* Cir. 225, U. S. Dept. Agr., June 1932, pp. 36.

MAXWELL, HU: *Uses of commercial woods of the United States; beech, birches, and maples.* Bul. 12, U. S. Dept. Agr., Oct. 1913, pp. 32–56.

RECORD, SAMUEL J.: Differentiating between maples. *Hardwood Record* (Chicago) 36: 6: 26–27, July 10, 1913.

ROSS, A. H. D.: Commercial importance of maple. *Canadian Lumberman and Woodworker* 35: 18: 36–37, Sept. 15, 1915.

58. Dogwood. *Cornus*, with nearly 50 species (mostly shrubs), is widely distributed in the northern hemisphere. Of the 16 or more species in the U. S., four reach tree size, but only two of them are of economic value. *C. Nuttallii* grows from California to British Columbia, being largest in the Redwood forests and near the shores of Puget Sound where it is frequently over 50, sometimes up to 100, feet tall and 1–2 feet in diameter. The timber is used to a small extent locally for tool handles, etc. *C. florida* is a smaller tree, common in the understory of the hardwood and Yellow Pine forests of eastern U. S. and at its best in the southern states. Its principal use (sapwood only) is for shuttles, and the normal annual consumption is about 15,500 cords; the supply in 1926 was estimated to be about 231,000 cords. Other uses are bobbins, golf-club heads, brush backs, mallets, and novelties.

CUNO, JOHN B.: *Utilization of dogwood and persimmon.* Bul. 1436, U. S. Dept. Agr., Sept. 1926, pp. 43.

RECORD, SAMUEL J., AND GEORGE A. GARRATT: *Boxwoods.* Bul. 14, Yale School of Forestry, 1925, pp. 71–75.

59. Cherry. *Prunus*, with about 120 species of Plum and Cherry trees and shrubs, is widely distributed over the temperate

regions of the northern hemisphere. Of the 22 species of tree size in the U. S. and Canada, only the Black Cherry, *P. serotina*, is of commercial importance for lumber. It is native to the eastern half of the U. S. and adjacent regions of Canada, being at its best in the southern Appalachians. It is a furniture and cabinet wood of the first class, but is less used for this purpose than formerly. It is extensively used for the backing of electrotypes, and for spirit levels, handsaw handles, and patterns.

60. Sycamore. *Platanus*, with several closely related species of large trees, grows in eastern and western North America and as far south as Central America, and in Europe, and southwestern Asia. The only American species of commercial importance is *P. occidentalis* (Sycamore, Buttonwood, Buttonball Tree). It is common along streams and lakes throughout the eastern half of the continent, being largest in the lower Ohio and Mississippi Valleys where it sometimes attains a height of 170 feet and a trunk diameter of 14 feet. Its principal uses are for boxes and crates, slack cooperage, furniture and fixtures, plywood, butchers' blocks, trunk slats, brushes, and woodenware. Quarter-sawed lumber is sometimes sold as Lacewood. The European species commonly planted along streets and in parks and known as the Plane Tree is *P. acerifolia* Willd. or a hybrid of *P. orientalis*. The woods of all species are much alike.

Brush, W. D.: Distinguishing characteristics of North American sycamore woods. *Botanical Gazette* 64: 6: 480–496, Dec. 1917.

Brush, W. D.: *Utilization of sycamore*. Bul. 884, U. S. Dept. Agr., Oct. 1920, pp. 24.

61. Beech. There are five species of *Fagus* in eastern Asia, one (*F. sylvatica* L.) in Europe, and one distributed over most of the eastern half of the U. S. and southeastern Canada. The estimated stand in the U. S. is about 8 billion board feet, three-fourths being in New England, New York, and Pennsylvania. The principal uses of the timber are boxes and crates, furniture (especially chairs), flooring, interior trim, turned handles, woodenware, laundry appliances, brushes, food containers, railway crossties (treated), distillate wood, and fuel. The terms Red Beech and White Beech are sometimes used to distinguish lighter and darker grades of the lumber. The wood of the European Beech is similar to that of the American.

Anonymous: *Beech.* U. S. Forest Service, June 1933, pp. 5.
Maxwell, Hu: *Uses of commercial woods of the United States; beech, birches, and maples.* Bul. 12, U. S. Dept. Agr., Oct. 1913, pp. 2–11.

62. Yellow Poplar. *Liriodendron,* with two almost identical species of tall trees, is found in central China and throughout most of the hardwood region of eastern United States and southern Ontario. It grows best in the Ohio Valley region and on the mountain slopes in North Carolina and Tennessee. It is often called Tulip Tree, and the timber, especially in New England and New York, is generally known as Whitewood. The estimated stand is about 10 billion board feet, 75 per cent of the first-growth timber being in the southern Appalachians. The wood is easy to work, nails without splitting, and holds paint exceptionally well. It is used extensively for sash, doors, painted interior trim, siding, boxes and crates, furniture (especially drawers, frames, etc.), fixtures, shelving, molding, plywood, and many other purposes.

Anonymous: *Yellow poplar.* U. S. Forest Service, May 1928, pp. 4.
Anonymous: The tulip or yellow poplar tree. *American Forestry* 21: 8: 833–840, Aug. 1915.
McLaughlin, R. P.: Systematic anatomy of the woods of the Magnoliaceae *Tropical Woods* 34: 3–39, June 1, 1933.

63. Cucumber and **Magnolia.** The genus *Magnolia,* with about 70 species of deciduous or evergreen trees and shrubs, is widely distributed in temperate North America and in eastern Asia. Many of them are highly ornamental. Of the nine species in the U. S., three are of more or less commercial importance. *M. acuminata* (Cucumber Tree or Mountain Magnolia) is most abundant and of its largest size in the mountains of the Carolinas and Tennessee. The lumber frequently is sold in mixture with Yellow Poplar, which it resembles in appearance, properties, and uses. *M. grandiflora* L. (Evergreen Magnolia) is common in the lowlands of Louisiana. Except for its greenish gray color, it bears more resemblance to Maple than to Yellow Poplar, for which it serves as a substitute to some extent. *M. virginiana* L., or *M. glauca* L. (Sweet or Swamp Bay) is a smaller tree, of the coastal swamps of the southeastern U. S. It is little used, except locally. Its heartwood is more distinctly brownish, the rays are larger, and the texture is coarser than in the preceding.

McLaughlin, R. P.: Some woods of the magnolia family. *Journal of Forestry* (Washington, D. C.) 26: 5: 665–677, May 1928.
Turner, H. B.: Magnolia; new commercial hardwood. *Southern Lumberman* (Nashville, Tennessee) 72: 952: 89–90, Dec. 20, 1913.

64. Basswood. *Tilia*, with its numerous species of small to large trees, is widely distributed in eastern North America, Europe, and eastern Asia. Botanists claim to recognize 18 species and 12 varieties of American Basswoods, but to the lumberman they are all of one kind, any differences being in the size of the trees and not the properties of the wood. Basswood lumber is preferred for products made of wood to be left in its natural condition, especially where a clean, attractive appearance, light weight, and freedom from odor are essentials, as in food containers (boxes, tubs, pails, veneer baskets). It is the favorite wood for apiarists' supplies, slack cooperage heading, and excelsior. A complete list of its uses would be very extensive. The wood is perishable when exposed to decay. The present total estimated stand of the timber in the U. S. is about 9 billion board feet, over half being in the Lake Superior region. The European species is called Linden.

Brush, W. D.: *Utilization of basswood.* Bul. 1007, U. S. Dept. Agr., June 1922, pp. 64.

65. Red Alder. *Alnus*, with about 20 species of shrubs and small to medium-sized trees, is very widely distributed in Europe and Asia and in the New World from Alaska to Bolivia. The principal European species are *A. glutinosa* Gaertn. and *A. incana* Moench; the timber is used chiefly for plywood, sabots, cooperage, and charcoal for black gunpowder. Of the six American species the only commercial one is the Red Alder of the Pacific Northwest, where it is the most important native hardwood. The wood is easy to work, but of plain appearance and not resistant to decay. It is used locally for the manufacture of turned and flat parts of the cheaper grades of furniture, for enameled work, plywood and core stock, and long handles. The estimated consumption in 1923 was less than 14 million board feet.

Johnson, H. M., E. J. Hanzlik, and W. H. Gibbons: *Red Alder in the Pacific Northwest.* Bul. 1437, U. S. Dept. Agr., Sept. 1926, pp. 46.

66. Apple. The Apple wood on the market is obtained from old orchards, and the supply is small and uncertain. The principal

use is for handsaw handles. The wood resembles that of Pear (*Pyrus communis* L.), but is not so fine textured.

Record, Samuel J.: Making handsaw handles. *Wood Worker* (Indianapolis, Ind.) 31: 10: 37–38, Dec. 1912.

67. Red Gum. *Liquidambar*, with about four species, occurs in Asia, and in North America from Connecticut south and southwestward into the highlands of Central America. A gum called storax is obtained from the bark of living trees. The timber commonly known in the American lumber trade as Gum or Red Gum, and in the furniture and allied industries as Gumwood, is the product of a single species belonging to the Witch Hazel family. Architects sometimes call it Hazelwood. In the European market the heartwood is generally sold as Satin Walnut and the sapwood (Sap Gum of the U. S. A.) frequently as Hazel Pine. The trees are largest and most abundant in river bottoms subject to inundation in the maritime region of the south Atlantic and Gulf States and in the lower Mississippi Valley. The wood is not resistant to decay and is inclined to warp, though quarter-sawing and careful seasoning largely overcome the latter defect. It is employed in large quantities for a wide range of uses, such as furniture, interior trim, doors, panels, background of display windows, and veneers for plywood, baskets, dishes, wire-bound boxes, and vegetable barrels. The lumber is often used in connection with Walnut in the less expensive classes of furniture. The consumption in 1926 was over one billion board feet. The supply is estimated at 35 billion feet.

Chittenden, A. K., and W. K. Hatt: *The red gum.* Bul. 58, U. S. Bu. Forestry, 1905, pp. 56.

Detwiler. S. B.: The red gum. *American Forestry* 22: 275: 641–647, Nov. 1916.

Gerry, Eloise: American storax production; results of different methods of tapping red gum trees. *Journ. Forestry* (Washington, D. C.) 19: 1: 15–24, Jan. 1921.

68. Black Gum and **Tupelo.** Tupelo, or Tupelo Gum, lumber is manufactured from trees of four species of *Nyssa*, namely, *N. aquatica* (Tupelo Gum), *N. sylvatica* (Black or Sour Gum, Tupelo, Pepperidge), *N. biflora* Walt. (Swamp Black Gum), and *N. ogeche* Marsh. (Sour Tupelo); the first two are of about equal proportions, the last two of minor importance. Black Gum lumber is mostly from *N. sylvatica*, but sometimes the name

is extended to the other species. Black Gum is scattered in both lowland and upland forests from Maine and Michigan to Florida and Texas. Tupelo Gum is a southern tree of the deep swamps, commonly associated with Cypress (*Taxodium*). The woods of all species are much alike, except that Black Gum usually is denser; they are light colored, tough to split, resistant to wear but not to decay, and difficult to season without warping. The principal uses are for boxes and crates, factory flooring, moldings, rollers, and veneer for plywood, boxes, and baskets; the timber is also used for railway crossties (treated) and for paper pulp. Some of it was formerly sold as Bay Poplar. The wood of the enlarged bases of Tupelo Gum is exceptionally light in weight and brittle, and is sometimes used for floats. There are two species of *Nyssa* in Asia.

Anonymous: *Tupelo.* U. S. Forest Service, May 1928, pp. 5.

Holroyd, H. B.: *The utilization of tupelo.* Cir. 40, U. S. Forest Service, 1906, pp. 16.

Sudworth, G. B., and C. D. Mell: *Distinguishing characteristics of North American gumwoods.* Bul. 103, U. S. Forest Service, Oct. 1911, pp. 20.

Von Schrenk, Hermann: *Tupelo; character, uses, treatment.* Reprinted from 25th anniversary ed. of the *Southern Lumberman*, Nashville, Tennessee, 1907, pp. 13.

Watson, G. E.: Tupelo; a substitute three years ago, now a standard wood established on its own merits. *Southern Lumberman* 68: 899: 76–90, Dec. 21, 1912.

69. Buckeye. *Aesculus*, with about 16 species of small to medium-sized trees, is represented in Europe, Asia, and North America. A commonly planted shade tree is the European *A. hippocastanum* L. (Horsechestnut). Of the six American species, one grows in California, the others in the central and southeastern parts of the U. S. Yellow Buckeye is the most common. The principal lumber production is in Tennessee, Kentucky, and Ohio. The annual consumption is unknown because the lumber is often sold in mixture with other species, especially as the sapwood of Yellow Poplar. It bears considerable resemblance to Basswood and is suitable for many of the same purposes.

Anonymous: The lowly buckeye. *Hardwood Record* 39: 1: 21, Oct. 25, 1914.

Holden, Ruth: Some features in the anatomy of the Sapindales. *Botanical Gazette* 53: 1: 50–58, Jan. 1912.

70. Willow. *Salix*, with more than 160 species of variable size from low shrubs to tall trees, is very widely distributed over the

world. The pliable young shoots of some species are used for making baskets and furniture. Well-known uses for the wood of the European species are cricket bats, artificial limbs, and charcoal for black gunpowder. Of the 25 North American species reaching tree size, only *Salix nigra* (Black Willow) is cut to any appreciable extent for lumber. It has a wide range, but is at its best in the rich bottomlands of the lower Mississippi and Ohio Rivers, where it is frequently 75 feet tall and 2–3 feet in diameter, occasionally much larger. The wood is not durable or attractive, but is tough and strong for its weight and keeps in place well. The lumber is used, though not very extensively, for boxes, crates, core stock for veneers, slack cooperage, excelsior, charcoal, and many of the same purposes as Cottonwood. It is sometimes sold as Brown Cottonwood and even as Swamp Walnut. Willow saplings are often woven into mats to protect river banks.

ANONYMOUS: Black willow; another "coming" wood. *Southern Lumberman* (Nashville, Tennessee) 72: 952: 90–91, Dec. 20, 1913.

DETWILER, S. B.: The willows; identification and characteristics. *American Forestry* 23: 277: 3–10, Jan. 1917.

LAMB, GEORGE N.: *Willows; their growth, use, and importance.* Bul. 316, U. S. Dept. Agr., Dec. 1915, pp. 52.

71. Poplar. *Populus*, with about 35 species, has an enormous range from the Arctic Circle throughout most of the north temperate zone, often forming extensive forests in the extreme north. The generic English name for the trees is Poplar, but in America they are usually divided into the Cottonwoods and the Aspens. In the timber trade, the lumber is classed as Cottonwood and the pulpwood as Poplar, regardless of species. There are 15 species of *Populus* in North America, and 6 of them are commercially important; the estimated stand of their timber in the U. S. is 10 billion board feet.

72. Cottonwood. *Populus deltoides* (Eastern Cottonwood, Carolina Poplar) is of scattered occurrence throughout the eastern half of the U. S. and often is planted for windbreaks, shade, and pulpwood. Heights of 75–85 feet and diameters of 2–3 feet are not unusual. The estimated stand of saw timber is $3\frac{1}{2}$ billion board feet. *P. heterophylla* (Swamp Cottonwood) grows in the south Atlantic and Gulf Coast region and the Mississippi Valley. Under favorable conditions trees reach a height of 100 feet in 40 years. Estimated stand $2\frac{1}{2}$ billion feet. *P. trichocarpa* (Black

Cottonwood) is the largest deciduous tree of the Pacific Coast and ranges from southern Alaska to southern California. Estimated stand in the U. S., $1\frac{1}{2}$ billion feet. *P. balsamifera* L. (Balsam Poplar, Balsam, Balm-of-Gilead) grows principally in Canada and Alaska, and at its best is a very large tree, sometimes 6 feet in diameter. It also occurs along the northern border of the U. S., but the trees are smaller. Estimated stand in the U. S. (a small part of the total) is a little over one billion feet. The principal uses of Cottonwood lumber are for boxes and crates, as it is light in weight but strong, nails without splitting, has a clean appearance, takes printing and stenciling well, and is odorless. Other uses are planing-mill products, woodenware, plywood, excelsior, and paper pulp, especially for high-grade book paper made by the soda process.

Anonymous: *Balsam poplar* and *Cottonwood.* U. S. Forest Service, Feb. 1928, pp. 3 and 6, resp.

Williams, A. W.: *Cottonwood in the Mississippi Valley.* Bul. 24, U. S. Dept. Agr., Dec. 1913, pp. 62.

73. Aspen. *Populus tremuloides* (Aspen, Quaking Aspen, Popple) grows throughout the northeastern quarter of the U. S. and the Rocky Mountains, and large portions of Canada and Alaska. *P. grandidentata* (Large-tooth Aspen, Popple) is limited to the northeastern part of the U. S. and southeastern Canada. Both are typically small to medium-sized trees, often growing in nearly pure stands, and their woods are practically identical. The total stand in the U. S. is estimated to be 12 billion board feet, of which about 2 per cent is large enough for lumber. The wood is employed mostly in making paper, especially for books and magazines. Other uses are excelsior, matches, and pails and boxes for containing food.

Anonymous: *Aspen.* U. S. For. Service, Feb. 1928, pp. 4.

Baker, F. S.: *Aspen in the Rocky Mountain region.* Bul. 1291, U. S. Dept. Agr., Feb. 1925, pp. 47.

Johnson, R. P. A., Jos. Kittredge, Jr., and Henry Schmitz: *Aspen; availability, properties, and utilization.* Technical Bul. 70, Univ. of Minnesota Agr. Exp. Sta., St. Paul, Aug. 1930, pp. 72.

Weigle, W. G., and E. H. Frothingham: *The aspens; their growth and management.* Bul. 73, U. S. Forest Service, May 1911, pp. 35.

General References

1. *Miscellaneous*

Anonymous: *American forests and forest products.* Statistical Bul. **21,** U. S. Dept. Agr., Washington, D. C., Oct. 1927, pp. 324.

Baterden, J. R.: *Timber.* New York, D. Van Nostrand & Co., 1908, pp. 351.

Boulger, G. S.: *Wood: A manual of the natural histories and industrial applications of the timbers of commerce.* (2d ed.) London, Edward Arnold, 1908, pp. 348.

Britton, N. L.: *North American trees.* New York, Henry Holt & Co., 1908, pp. 894.

Brown, H. P.: *Atlas of the commercial woods of the United States.* Bul. New York State College of Forestry, Syracuse, Sept. 1928, pp. 6, pls. 60.

Brown, Nelson C.: *Forest products; their manufacture and use.* (2d ed. rev.) New York, John Wiley & Sons, Inc., 1927, pp. 447.

Chalk, L., and B. J. Rendle: *British hardwoods; their structure and identification.* Forest Products Research Bul. 3, Dept. Sci. & Ind. Research and Imp. For. Institute, London, 1929, pp. 53.

Charpentier, Paul: *Timber: A comprehensive study of wood in all its aspects.* (Translated from the French by Joseph Kennell.) London, Scott, Greenwood & Co., 1902, pp. 437.

Deam, Chas. C.: *Trees of Indiana.* Pub. No. 13, Indiana Dept. Conservation, Indianapolis, 1921, pp. 317.

Elliott, S. B.: *The important timber trees of the United States.* Boston and New York, Houghton Mifflin Co., 1912, pp. 382.

Forsaith, C. C.: *The technology of New York State timbers.* Tech. Bul. 18, New York State College of Forestry, Syracuse, Sept. 1926, pp. 374.

Garrratt, George A.: *Mechanical properties of wood.* New York, John Wiley & Sons, Inc., 1931, pp. 276.

Gibson, Henry H., and Hu Maxwell: American forest trees. Chicago, *Hardwood Record,* 1913, pp. 708.

Hale, J. D.: *The identification of woods commonly used in Canada.* Bul. 81, Canadian Forest Service, Ottawa, 1932, pp. 48.

Hayward, Phillips A.: *Wood: Lumber and timbers.* New York, Chandler Cyclopedia, 1930, pp. 521.

Holtman, Dudley F.: *Wood construction; principles, practice, details.* New York, McGraw-Hill Book Co., Inc., 1929, pp. 711.

Hough, Romeyn B.: *American woods.* (Sections and text.) Vols. 1–13, Lowville, New York, the author, 1893–1913.

Hough, Romeyn B.: *Handbook of the trees of the northern states and Canada east of the Rocky Mountains.* Lowville, New York, the author, 1907, pp. 470.

Howard, Alexander L.: *A manual of the timbers of the world; their characteristics and uses.* (Rev. ed.) London, Macmillan & Co., Ltd., 1934, pp. 672.

Illick, Joseph S.: *Pennsylvania trees.* Bul. 11, Pennsylvania Dept. Forests and Waters, Harrisburg, 1928, pp. 237.

Jeffrey, Edward C.: *The anatomy of woody plants.* Chicago, Univ. of Chicago Press, 1917, pp. 478.

Jepson, Willis L.: *The silva of California.* (Vol. II, Memoirs of the University of California.) Berkeley, Univ. Press, 1910, pp. 480.

Jones, W. S.: The structure of the timbers of some common genera of coniferous trees. *Quarterly Journal of Forestry* (London) 6: 2: 112–134, April 1912.

Kellogg, R. S.: *Lumber and its uses.* New York, U.P.C. Book Co., Inc., 1924, pp. 370.

Kellogg, Royal S.: *Pulpwood and wood pulp in North America.* New York, McGraw-Hill Book Co., Inc., 1923, pp. 273.

Koehler, Arthur: *Guidebook for the identification of woods used for ties and timbers.* U. S. Forest Service, Washington, D. C., 1917, pp. 79, pls. 31.

Koehler, Arthur: *The properties and uses of wood.* New York, McGraw-Hill Book Co., Inc., 1924, pp. 354.

Krais, Paul: *Gewerbliche Materialkunde; die Hölzer.* Stuttgart, Felix Krais, 1910, pp. 782.

Laslett, Thomas: *Timber and timber trees, native and foreign.* (2d ed., revised and enlarged by H. Marshall Ward). London, Macmillan & Co., 1894, pp. 442.

Lee, H. N.: *Canadian woods for structural timbers.* Bul. 59, For. Branch, Dept. Interior Canada, Ottawa, 1917, pp. 44.

Markwardt, L. J.: *The distribution and the mechanical properties of Alaska woods.* Technical Bul. 226, U. S. Dept. Agr. Washington, D. C., Feb. 1931, pp. 80.

Markwardt, L. J.: *Comparative strength properties of woods grown in the United States.* Tech. Bul. No. 158, U. S. Dept. Agr., Washington, D. C., 1930, pp. 39.

McElhanney, T. A., and R. S. Perry: *Some commercial softwoods of British Columbia; their mechanical and physical properties.* Bul. 78, Canadian Forest Service, Ottawa, 1927, pp. 45.

Newlin, J. A., and Thomas R. C. Wilson: *Mechanical properties of woods grown in the United States.* Bul. No. 556, U. S. Dept. Agr., Washington, D. C., 1917, pp. 47.

Penhallow, David P.: *A manual of the North American Gymnosperms, exclusive of the Cycadales, but together with certain exotic species.* Boston, Ginn & Co., 1907, pp. 374.

Piccioli, Lodovico: *Technologia del legno.* Torino, 1919, pp. 416.

PRATT, MERRITT B.: *The use of lumber on California farms.* Bul. 299, Agr. Exp. Sta., Berkeley, 1918, pp. 121.

ROCHESTER, G. H.: *The mechanical properties of Canadian woods, together with their related physical properties.* Bul. 82, Canadian Forest Service, Ottawa, 1933, pp. 88.

RECORD, SAMUEL J.: *The mechanical properties of wood.* New York, John Wiley & Sons, Inc., 1914, pp. 165.

RECORD, SAMUEL J.: *Timbers of tropical America.* New Haven, Yale Univ. Press, 1924, pp. 610.

ROTH, FILIBERT: *Timber: An elementary discussion of the characteristics and properties of woods.* Bul. No. 10, U. S. Div. of Forestry, Washington, D. C., 1895, pp. 88.

SARGENT, CHAS. S.: *Manual of the trees of North America (exclusive of Mexico).* Boston and New York, Houghton Mifflin Co., 1922, pp. 910.

SARGENT, CHAS. S.: *Report on the forests of North America (exclusive of Mexico).* Vol. 9, Tenth Census, Washington, D. C., 1884, pp. 612.

SARGENT, CHAS. S.: *The silva of North America: A description of the trees which grow naturally in North America, exclusive of Mexico.* Vols. 1–14. Boston and New York, Houghton Mifflin Co., 1891–1902.

SARGENT, CHAS. S.: *The woods of the United States, with an account of the structure, qualities, and uses* (Jesup collection). New York, D. Appleton & Co., 1885, pp. 203.

SNOW, CHARLES H.: *The principal species of wood.* (2d ed.) New York, John Wiley & Sons, Inc., 1910, pp. 212.

SNOW, CHARLES H.: *Wood and other organic structural materials.* New York, McGraw-Hill Book Co., 1917, pp. 478.

SOLEREDER, HANS: *Systematic anatomy of the Dicotyledons.* Oxford, Clarendon Press, 1908, pp. 1182.

STEVENSON, WILLIAM: *The trees of commerce.* (Rev. ed.) London, W. Rider & Son, 1908, pp. 274.

STONE, HERBERT: *The timbers of commerce and their identification.* London, W. Rider & Son, 1904, pp. 311.

SUDWORTH, GEORGE B.: *Forest trees of the Pacific slope.* U. S. Forest Service, Washington, D. C., 1908, pp. 441.

SUDWORTH, GEORGE B.: *Miscellaneous conifers of the Rocky Mountain region.* Bul. No. 680, U. S. Dept. Agr., Washington, D. C., 1918, pp. 45, 9 maps.

SUDWORTH, GEORGE B.: *The pine trees of the Rocky Mountain region.* Bul. No. 460, U. S. Dept. Agr., Washington, D. C., 1917, pp. 47, 14 maps.

TRAYER, GEORGE W.: *Wood in aircraft construction; supply, suitability, handling, fabrication, design.* Washington, D. C., Nat'l. Lumber Manufacturers Ass'n, 1930, pp. 276.

WELLS, S. D., and J. D. RUE: *The suitability of American woods for paper pulp.* Bul. 1485, U. S. Dept. Agr., Washington, D. C., May 1927, pp. 102.

WIESNER, JULIUS: *Die Rohstoffe des Pflanzen Reiches.* Vol. 2. Leipzig, Wilhelm Engelmann, 1903, pp. 1070.

WILDA, HERMANN: *Das Holz: Aufbau, Eigenschaften und Verwendung.* (2d ed.) Leipzig, G. J. Göschen, 1920, pp. 154.

2. *Wood-using Industries*

ARMSTRONG, ANDREW K.: *Wood-using industries of California.* Bul. No. 3, California State Board of Forestry, Sacramento, 1912, pp. 114.

BESLEY, F. W., and J. G. DORRANCE: *The wood-using industries of Maryland.* Pub. by Maryland State Bd. of Forestry, Baltimore, 1919, pp. 122.

BROOKS, A. B.: *Wood manufacturing industries of West Virginia.* Vol. 5, Chap. 9, pp. 430–461, West Virginia Geological Survey, Morgantown, 1910.

DOWNS, J. B., and C. B. GUTCHESS: *The wood-using industries of Massachusetts.* Bul. No. 12, Harvard Forest, Petersham, 1928, pp. 85.

DUNNING, C. W.: The wood-using industries of Idaho. *Pacific Lumber Trade Journal* (Seattle), July 1912.

DUNNING, C. W.: *Wood-using industries of Ohio.* Pub. by Ohio Agr. Exp. Sta., Wooster, 1912, pp. 133.

FLETCHER, E. D., and AUSTIN F. HAWES: *The use of lumber and wood in Connecticut.* Hartford, 1928, pp. 51.

FOWLER, W. A., and R. H. ROBNETT: *Oregon hardwood industries.* No. 4, Business Adm. Series, Univ. of Oregon, Eugene, 1929, pp. 96.

GOULD, C. W., and HU MAXWELL: The wood-using industries of Mississippi. *Lumber Trade Journal* (New Orleans) 61: 6: 19–29, March 15, 1912.

GOULD, CLARK W., and HU MAXWELL: The wood-using industries of Tennessee. *The Southern Lumberman* (Nashville) 66: 870: 39–52, May 25, 1912.

HARRIS, JOHN T.: *Wood-using industries of New York.* Series 14, No. 2, New York State College of Forestry, Syracuse, 1913, pp. 213.

HARRIS, JOHN T., and HU MAXWELL: The wood-using industries of Alabama. *Lumber Trade Journal* (New Orleans) 61: 9: 19 30, May 1, 1912.

HARRIS, J. T., HU MAXWELL, and FRANCIS KIEFER: *Wood-using industries and national forests of Arkansas.* Bul. 106, U. S. Forest Service, Washington, D. C., 1912, pp. 40.

HATCH, CHARLES F., and HU MAXWELL: The wood-using industries of Missouri. *St. Louis Lumberman* 49: 6: 68–82, March 15, 1912.

HELPHENSTINE, R. K.: *Wood-using industries of North Carolina.* Bul. No. 30, North Carolina Geol. and Econ. Survey, Chapel Hill, 1923, pp. 105.

HOFFMAN, B. E.: Alaska woods, their present and prospective uses. *Forestry Quarterly* 11: 2: 185–200, June 1913.

HOYLE, RAYMOND J.: *Wood-using industries of New York.* Tech. Pub. No. 27, New York State College of Forestry, Syracuse, 1928, pp. 160.

KNAPP, JOSEPH BURKE: Montana's secondary wood-using industries. *The Timberman* (Portland, Ore.) 14: 1: 52–55, Nov. 1912.

Lewis, R. G., and W. Guy H. Boyce: *Wood-using industries of the maritime provinces.* Bul. No. 44, Forestry Branch, Dept. of Interior Canada, Ottawa, 1914, pp. 100.

Lewis, R. G., and W. Guy H. Boyce: *Wood-using industries of Ontario.* Bul. No. 36, Forestry Branch, Dept. Interior Canada, Ottawa, 1913, pp. 127.

Lewis, R. G., and W. Guy H. Boyce: *Wood-using industries of the prairie provinces.* Bul. No. 50, Forestry Branch, Dept. Interior Canada, Ottawa, 1915, pp. 75.

Lewis, R. G., and J. A. Doucet: *Wood-using industries of Quebec.* Bul. No. 63, Forestry Branch, Dept. Interior Canada, Ottawa, 1918, pp. 89.

Lewis, R. G., and A. E. Millward: *Wood-using industries of Ontario. II.* Bul. No. 75, Forestry Branch, Dept. Interior Canada, Ottawa, 1924, pp. 106.

Lodewick, J. Elton: *Wood-using industries of Virginia.* Bul. No. 21, Eng. Ext. Div. Series, Virginia Polytechnic Inst., Blacksburg, 1929, pp. 169.

MacMillan, H. R.: *Wood-using industries, 1910.* Bul. No. 24, Forestry Branch, Dept. Interior Canada, Ottawa, 1912, pp. 42.

Maxwell, Hu: *Wood-using industries of Florida.* Pub. by Florida Dept. of Agr., Tallahassee, 1912, pp. 85.

Maxwell, Hu: The wood-using industries of Louisiana. *Lumber Trade Journal* (New Orleans) 61: 1: 19–33, Jan 1, 1912.

Maxwell, Hu: *The wood-using industries of Maryland.* Pub. by Maryland State Board of Forestry, Baltimore, 1910, pp. 49.

Maxwell, Hu: *A study of the Massachusetts wood-using industries.* Pub. by State of Massachusetts, Boston, 1910, pp. 38.

Maxwell, Hu: *Wood-using industries of Michigan.* Pub. by Public Domain Commission, Lansing, 1912, pp. 101.

Maxwell, Hu, and John T. Harris: *The wood-using industries of Iowa.* Bul. No. 142, Agr. Exp. Sta., Iowa State College of Agr. and Mechanic Arts, Ames, 1913, pp. 289.

Maxwell, Hu, and John T. Harris: *Wood-using industries of Minnesota.* Pub. by Minnesota State Forestry Board, St. Paul, 1913, pp. 79.

Maxwell, Hu, and John T. Harris: *Wood-using industries of Vermont.* Forestry Pub. No. 11, Vermont Dept. of Agr. and Forestry, Rutland, 1913, pp. 119.

Maxwell, Hu, and Charles F. Hatch: The wood-using industries of Texas. *Lumber Trade Journal* (New Orleans) 61: 12: 27–44, June 15, 1912.

Nellis, J. C.: The wood-using industries of Indiana. *Hardwood Record* (Chicago) 40: 10, Sept. 10, 1915 to 51: 8, Feb. 10, 1916.

Nellis, J. C.: *The wood-using industries of Maine.* Report of Forest Commissioner, Waterville, 1912, pp. 85-188.

Nellis, J. C., and J. T. Harris: *Wood-using industries of West Virginia.* Bul. No. 10, West Virginia Dept. Agr., Charleston, 1913, pp. 144.

Oakleaf, Howard B.: *Wood-using industries of Oregon, with special reference to the properties and uses of Oregon woods.* Pub. by Oregon Conservation Ass'n, Portland, 1911, pp. 46.

OAKLEAF, HOWARD B.: Washington's secondary wood-using industries. *Pacific Lumber Trade Journal* (Seattle), Nov. 1911, pp. 22–27, 29, 30.

PACKER, B. G.: *Wisconsin's wood-using industries.* Bul. No. 67, Wisconsin Dept. Agr., Madison, 1925, pp. 58.

PIERSON, ALBERT H.: *Wood-using industries of Connecticut.* For. Pub. No. 7, Bul. 174, Connecticut Agr. Exp. Sta., New Haven, Jan. 1913, pp. 96.

PIERSON, ALBERT H.: *Wood-using industries of New Jersey.* Pub. by Forest Park Reservation Com. of New Jersey, Union Hill, 1914, pp. 63.

REES, LOUIS W.: *Lumber production and wood utilization in southeastern Minnesota, with special reference to the farm woodlot.* Bul. No. 271, Agr. Exp. Sta., Univ. Minnesota, University Farm, St. Paul, 1930, pp. 28.

REYNOLDS, R. V., and R. J. HOYLE: *Wood-using industries of New York.* Tech. Pub. No. 14, New York State College of Forestry, Syracuse, 1921, pp. 231.

SIMMONS, ROGER E.: *The wood-using industries of Illinois.* Pub. by Univ. of Illinois, Urbana, 1911, pp. 164.

SIMMONS, ROGER E.: *A study of the wood-using industries of Kentucky.* Pub. by Dept. Agr., Labor and Statistics, Frankfort, 1910, pp. 74.

SIMMONS, ROGER E.: *Wood-using industries of New Hampshire.* Pub. by New Hampshire Forestry Commission, Concord, 1912, pp. 111.

SIMMONS, ROGER E.: *Wood-using industries of North Carolina.* Econ. Paper No. 20, North Carolina Econ. and Geol. Survey, Raleigh, 1910, pp. 74.

SIMMONS, ROGER E.: *Wood-using industries of Pennsylvania.* Bul. No. 9, Dept. of Forestry, Harrisburg, April 1914, pp. 204.

SIMMONS, ROGER E.: *Wood-using industries of Virginia.* Pub. by Dept. of Agr. and Immigration, Richmond, 1912, pp. 88.

SMITH, FRANKLIN H.: *A study of the Wisconsin wood-using industries.* Pub. by Forestry Dept., Madison, 1910, pp. 68.

SWAN, O. T.: The wood-using industries of Georgia. *Lumber Trade Journal* (New Orleans) 67: 6: 19–29, Mar. 15, 1913.

WOLFE, STANLEY L.: *Wood-using industries of South Carolina.* Pub. by Dept. of Agr., Commerce and Industries, Columbia, 1913, pp. 53.

INDEX

DESCRIPTION OF PLATES

All photomicrographs show magnification of 50 diameters

PLATE I.

DESCRIPTION OF PLATE I.

Map of the United States showing Natural Forest Regions.

PLATE I.

Map of the United States showing Natural Forest Regions. (U. S. Forest Service.)

PLATE II.

DESCRIPTION OF PLATE II

Fig. 1. — *Taxodium distichum* (Bald Cypress). Cross section through the junction of two growth rings, showing narrow late wood. Several parenchyma cells are visible near the lower edge.

Fig. 2. — *Tsuga canadensis* (Eastern Hemlock). Cross section showing decided contrast between the late wood of one growth ring and the early wood of the next.

Fig. 3. — *Juniperus virginiana* (Red Cedar). Cross section through the median portion of a growth ring, showing zonate arrangement of parenchyma cells.

Fig. 4. — Same wood. Cross section showing normal and abnormal late wood, the latter giving rise to a double growth ring (two false growth rings). Note the small size of the cells of *Juniperus* (fine texture) in comparison with those of *Taxodium* and *Tsuga* above.

Fig. 5. — *Quercus alba* (White Oak). Cross section showing numerous small, thin-walled, angular pores surrounded by parenchyma in late wood of one season's growth, and large pores with tyloses in early wood of the next season.

Fig. 6. — *Quercus borealis maxima* (Red Oak). Section comparable to preceding, showing few small, thick-walled, circular pores in the late wood and large pores without tyloses in early wood.

PLATE II.

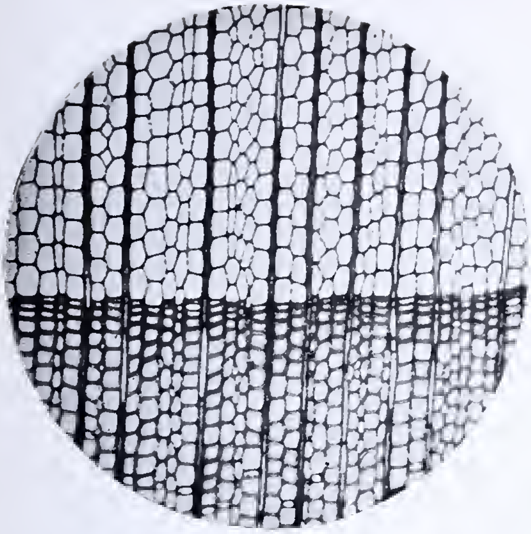


Fig. 1

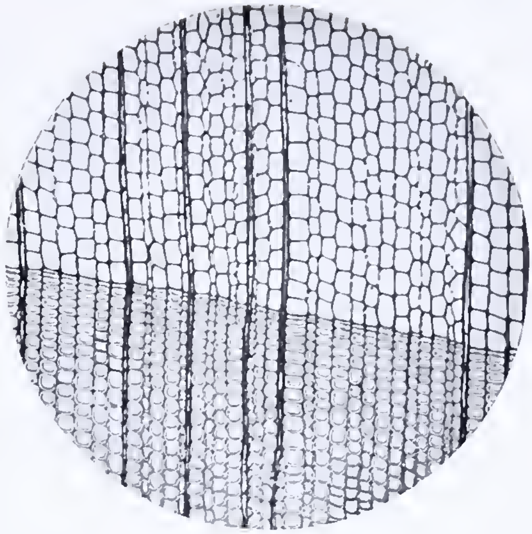


Fig. 2

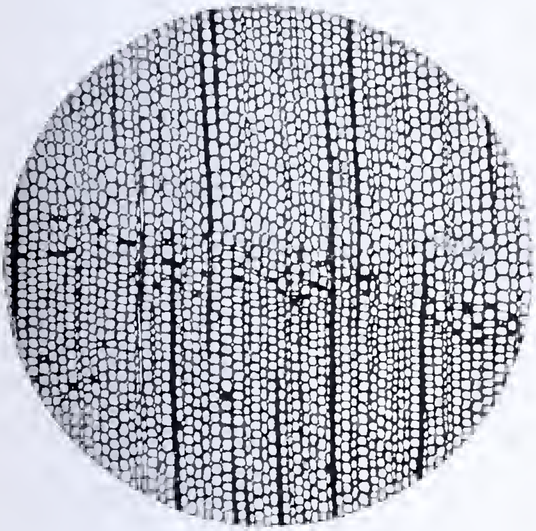


Fig. 3

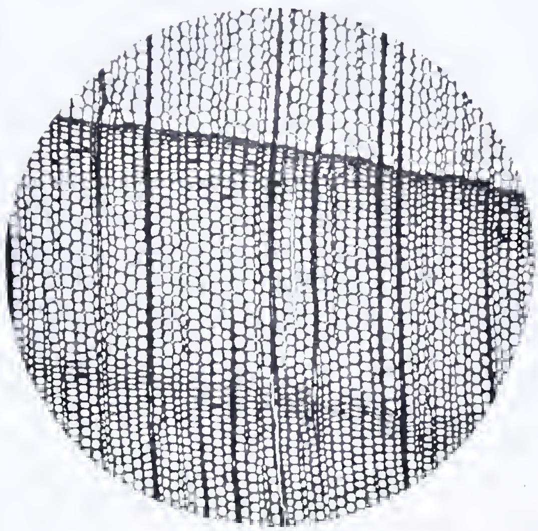


Fig. 4

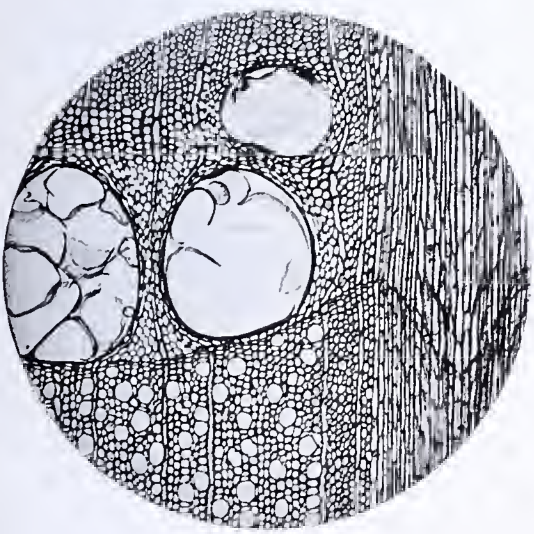


Fig. 5

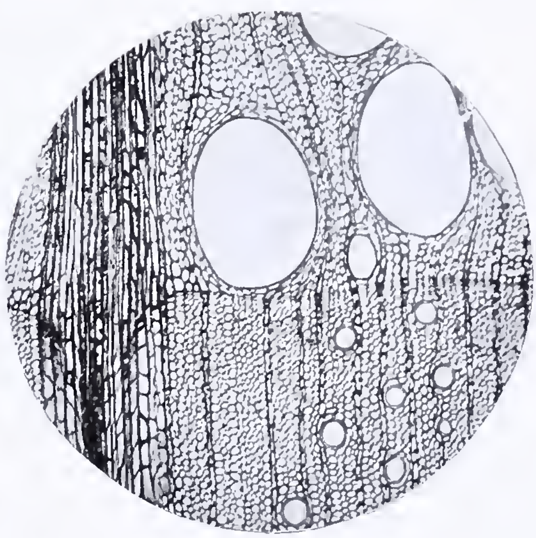


Fig. 6

PLATE III.

DESCRIPTION OF PLATE III

Fig. 1. — *Quercus alba* (White Oak). Tangential section showing one large ray and numerous uniseriate rays; also thick-walled wood fibers, a small vessel, and a few parenchyma strands.

Fig. 2. — *Ulmus americana* (White Elm). Cross section showing large pores in a single row, small pores in irregular concentric bands broken into clusters by the rays. The dark areas are composed of thick-walled libriform fibers.

Fig. 3. — *Robinia pseudoacacia* (Black Locust). Cross section showing dense areas of libriform fibers and two clusters of pores surrounded by paratracheal parenchyma in late wood, and abundant parenchyma and large pores (filled with tyloses) in early wood.

Fig. 4. — *Toxylon pomiferum* (Osage Orange). Radial section showing vessels filled with tyloses; also vertical wood parenchyma, heterogeneous ray, and some thick-walled libriform fibers.

Fig. 5. — *Gymnocladus dioicus* (Kentucky Coffee-tree). Cross section showing clusters of comparatively large pores in late wood.

Fig. 6. — *Gleditsia triacanthos* (Honey Locust). Similar section showing minute pores in late wood.

PLATE III.

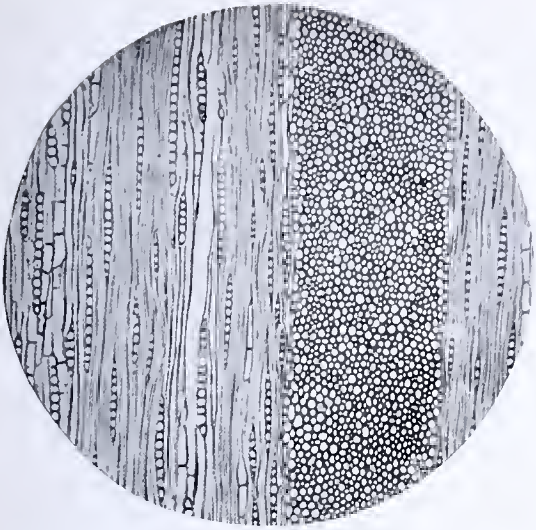


FIG. 1

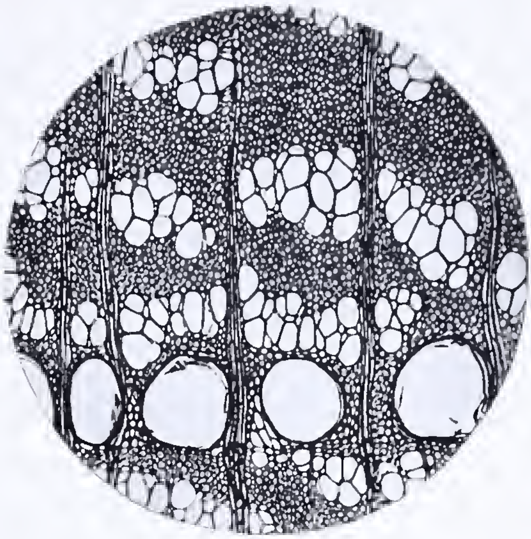


FIG. 2

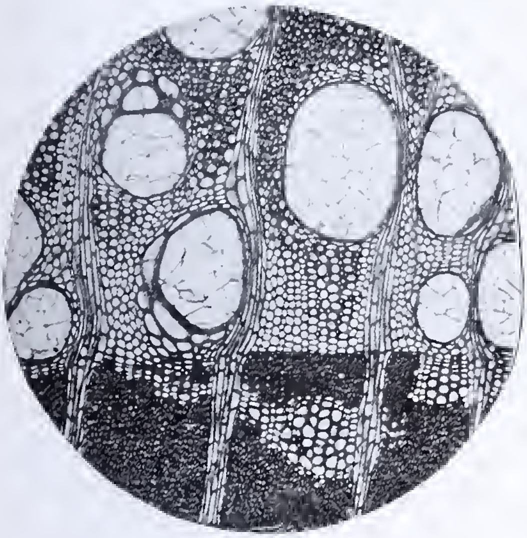


FIG. 3

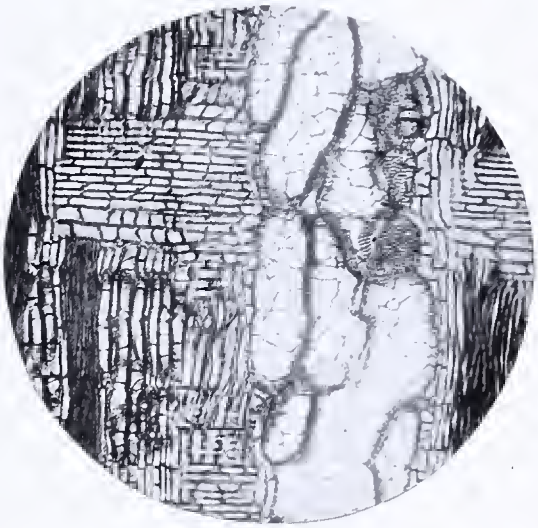


FIG. 4

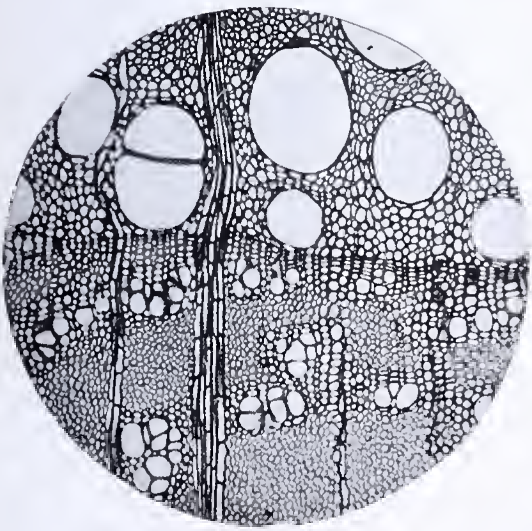


FIG. 5

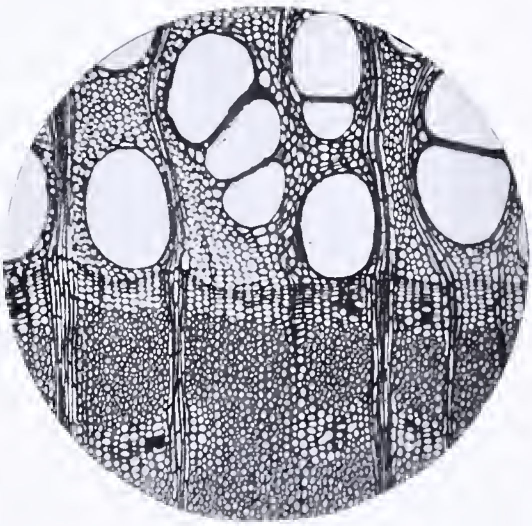


FIG. 6

PLATE IV.

DESCRIPTION OF PLATE IV

Fig. 1. — *Hicoria ovata* (Shagbark Hickory). Cross section showing ground mass of thick-walled fiber-tracheids, distinct lines of metatracheal parenchyma, and large pores with tyloses.

Fig. 2. — *Diospyros virginiana* (Persimmon). Cross section showing rather indistinct lines of metatracheal parenchyma, and pores without tyloses.

Fig. 3. — *Hicoria pecan* (Pecan Hickory). Tangential section showing rays irregular in size and arrangement. Three large crystals of calcium oxalate and numerous fiber-tracheids and parenchyma strands are visible.

Fig. 4. — *Diospyros virginiana* (Persimmon). Tangential section showing rays of fairly uniform height in storied arrangement.

Fig. 5. — Same wood. Radial section showing vessel members, parenchyma strands, fiber-tracheids, and rays in storied arrangement.

Fig. 6. — *Juglans nigra* (Black Walnut). Radial section showing a vessel (with tyloses), homogeneous rays, and a background of fiber-tracheids and parenchyma strands (some of them crystalliferous).

PLATE IV

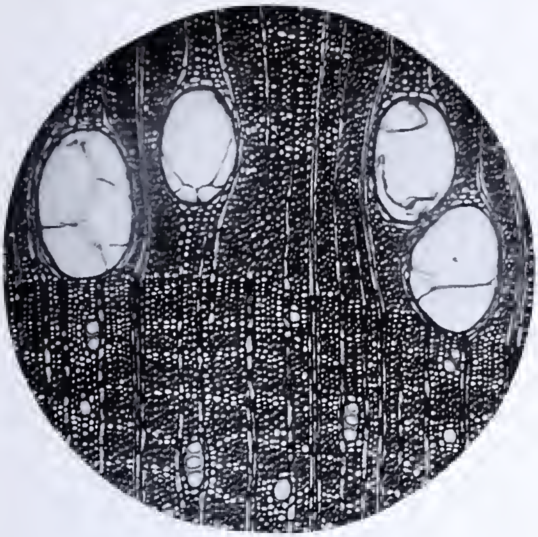


FIG. 1

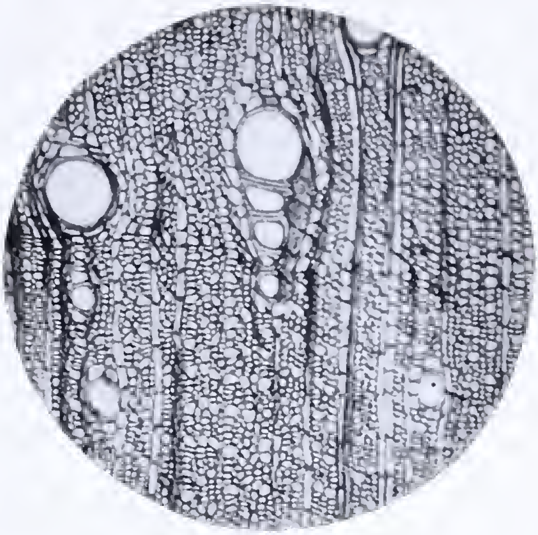


FIG. 2

FIG. 3

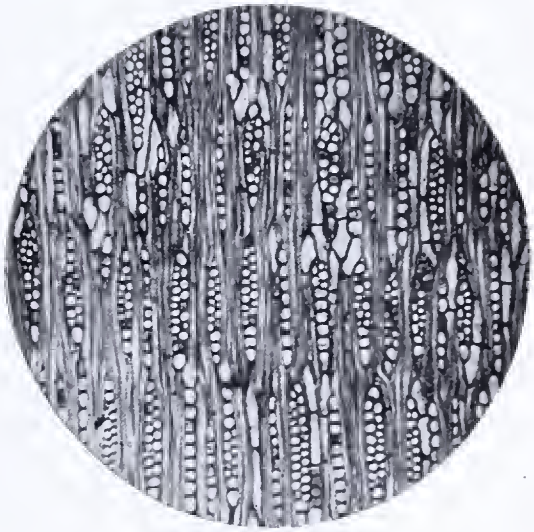


FIG. 4

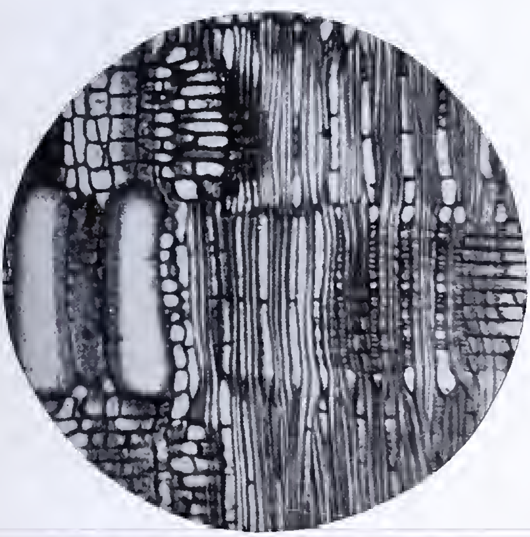


FIG. 5

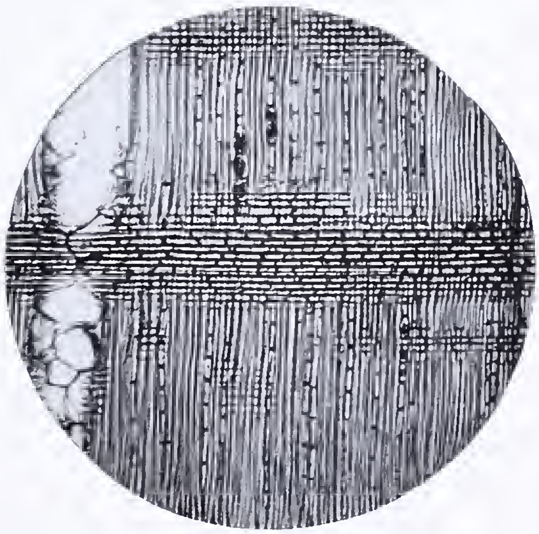


FIG. 6

PLATE V.

DESCRIPTION OF PLATE V

Fig. 1. — *Morus rubra* (Red Mulberry). Cross section showing arrangement of pores in late wood, width of rays, and presence of tyloses in large pores.

Fig. 2. — *Fraxinus nigra* (Black Ash). Cross section showing isolated pores in late wood not joined tangentially by wood parenchyma. Outer margin of growth ring composed of thin layer of wood parenchyma.

Fig. 3. — *Alnus oregona* (Red Alder). Cross section showing aggregate ray and distribution of pores.

Fig. 4. — Same wood. Tangential section showing aggregate ray, intermediate uniseriate rays, vessels, wood fibers, and wood-parenchyma strands.

Fig. 5. — *Betula lenta* (Sweet or Black Birch). Cross section showing size and distribution of pores and width of rays. Note wood-parenchyma cells, diffuse or in short tangential lines.

Fig. 6. — *Ostrya virginiana* (Hop Hornbeam). Cross section showing size and arrangement of pores and distribution of wood-parenchyma cells in inconspicuous tangential lines.

PLATE V

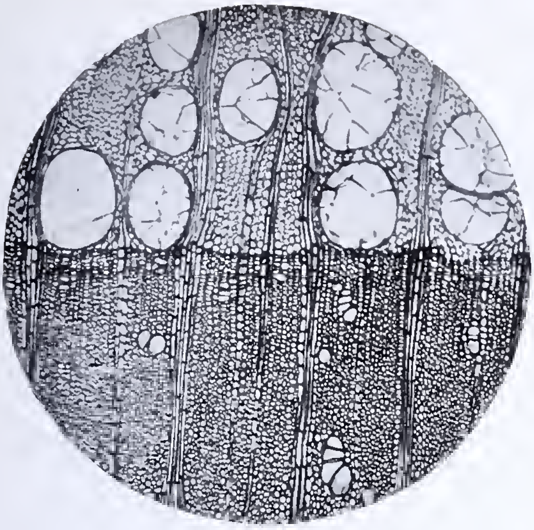


Fig. 1

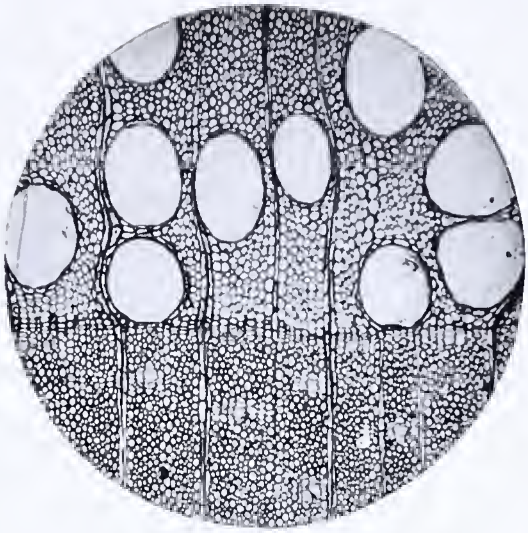


Fig. 2

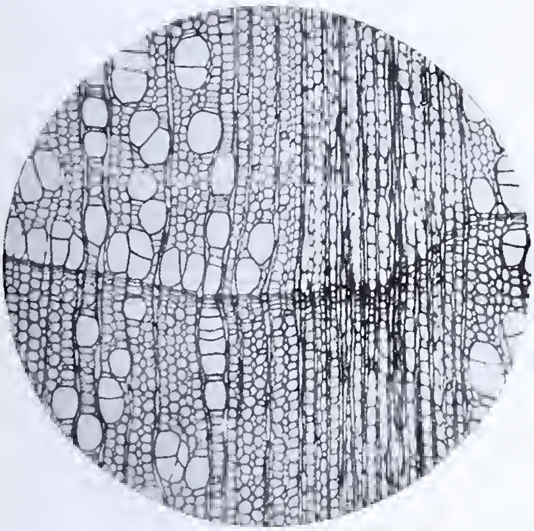


Fig. 3

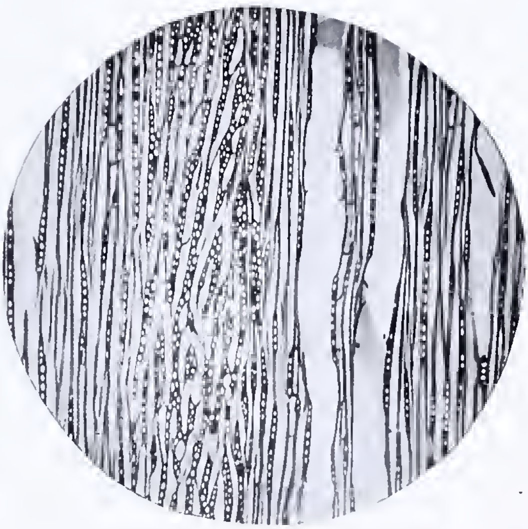


Fig. 4

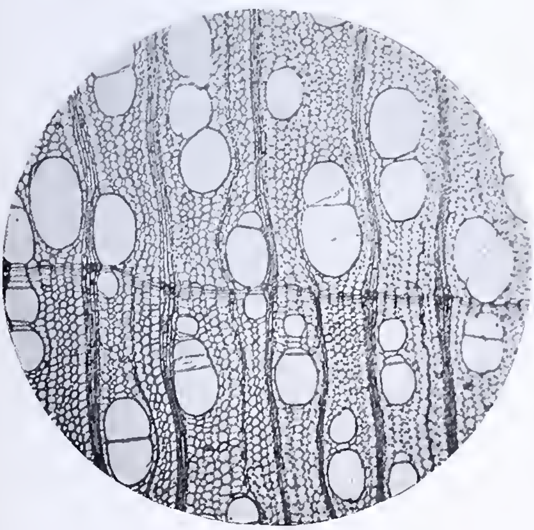


Fig. 5

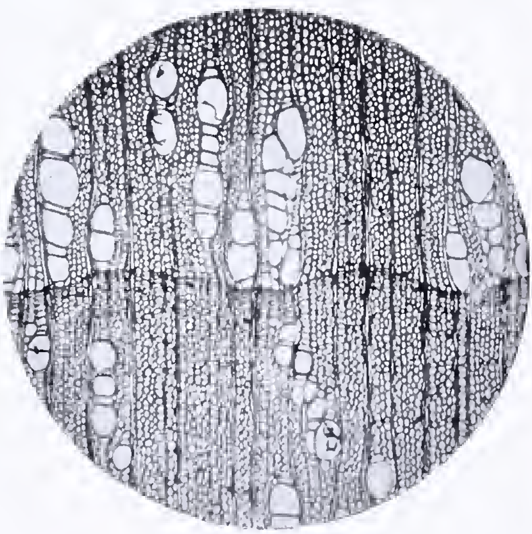


Fig. 6

PLATE VI.

DESCRIPTION OF PLATE VI

FIG. 1. — *Liquidambar styraciflua* (Red or Sweet Gum). Cross section showing size and distribution of pores, width of rays, and arrangement of wood fibers in radial rows.

FIG. 2. — *Liriodendron tulipifera* (Yellow Poplar or Tulip-tree). Cross section showing size and distribution of pores, and thin layer of terminal parenchyma.

FIG. 3. — *Magnolia acuminata* (Cucumber Tree). Tangential section showing vessel members with scalariform pitting, and the small biseriate rays.

FIG. 4. — *Liriodendron tulipifera.* Tangential section showing vessels with ordinary bordered pits, and the comparatively large 3–5-seriate rays.

FIG. 5. — *Aesculus glabra* (Ohio Buckeye). Cross section showing uniform distribution of pores and rays.

FIG. 6. — Same wood. Tangential section showing very fine uniseriate rays, irregularly disposed.

PLATE VI

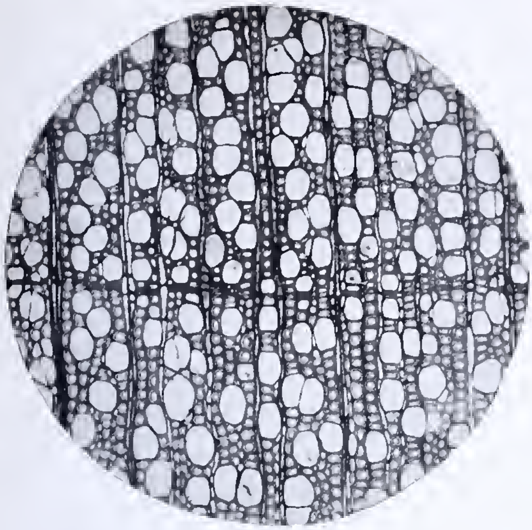


FIG. 1

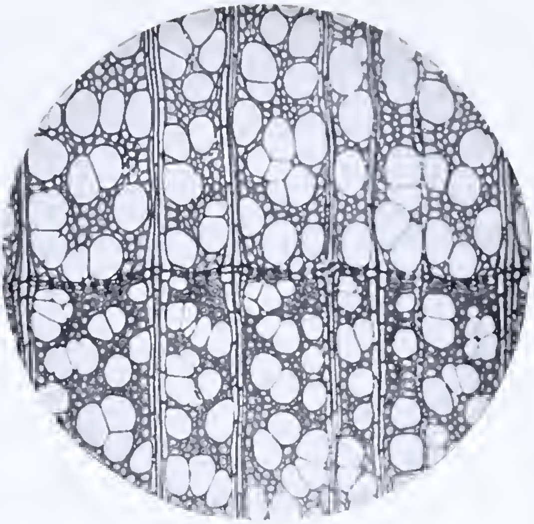


FIG. 2


FIG. 3


FIG. 4

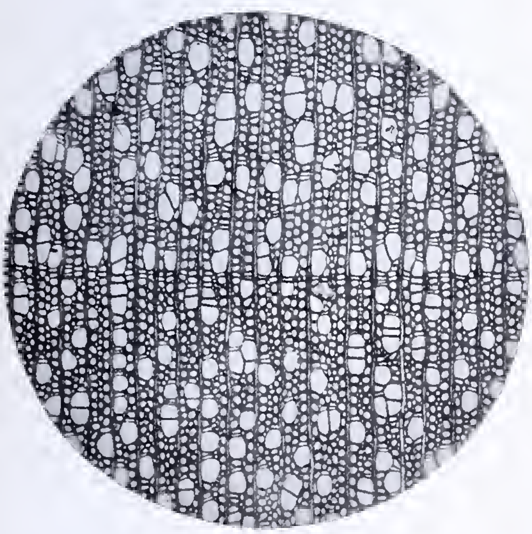


FIG. 5


FIG. 6

$2,12

8/16/34